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A DISCUSSION OF SOME OF THE ANEMOGRAPHIC OBSERVATIONS RECORDED AT MADRAS.

BY

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METEOROLOGIST, MADRAS

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A DISCUSSION OF SOME OF THE ANEMOGRAPHIC OBSERVATIONS RECORDED AT MADRAS; BY R. LL. JONES, M.A., METEOROLOGIST, MADRAS

CONTENTS.

A.—THE ANEMOMETER AND ITS RECORDS.

B.—THE AIR MOVEMENT IRRESPECTIVE OF DIRECTION.

C.—THE AIR MOVEMENT IN DIRECTION AND MAGNITUDE.

CONTENTS—*concld.*

A discussion of some of the Anemographic Observations recorded at Madras; by R. Ll. Jones, M. A., Meteorologist, Madras.

Introduction.

1. The following paper contains an analysis of some of the wind records taken by a Beckley Anemograph at the Madras observatory, a discussion of some of the most prominent features of the air movements revealed by them, and of the relation of these to the general meteorological conditions over southern India. Two volumes dealing with the meteorological observations that have been regularly made at the observatory since 1860 have been already published. The first is entitled "Results of the Meteorological Observations made at the Government Observatory, Madras, during the years 1861-1890" and the second "Madras Observatory Daily Meteorological Means." In the introduction to the second volume, issued in 1896, a fuller discussion of the observations is stated to be desirable. The following paper is a contribution towards this object and towards the discussion and correlation of the more important air movements over India as a whole, which is now being carried out by Sir John Eliot.

Geographical features.

2. The observatory where the records here discussed were taken is in Lat. 13° 4′N., Long 80° 15′E. and is at a distance of three miles from the sea. The surrounding country is very flat in all directions and the nearest hills of any considerable elevation are the Naggery Hills situated at about 50 miles to the north-west. To the westward of the Madras coast the country rises gradually forming the plains of the Carnatic. At some distance to the north of Madras the Eastern Ghâts trend off to the westward. These form the edge of the Mysore plateau and at their junction with the Western Ghâts the plateau of the Nilgiri Hills. The Coromandel coast runs nearly due north from Point Calimere to near Masulipatam, a distance of about 350 miles, and Madras is situated near the middle of this coast line. Its position and the geographical character of the surrounding country are thus in marked contrast to those of stations on the west coast. On that coast there is but a very narrow strip of low lying country between the range of the Western Ghâts and the sea. On the east coast on the other hand, the plain forming the province of the Carnatic, as far north as Madras occupies from one-half to one-third of the width of the Peninsula; on the west coast the rise of the hills is abrupt to their maximum of six to seven thousand feet while from the east coast it is very gradual.

The anemometer.

3. The instrument with which the records have been made at Madras is a Beckley anemograph, which has been in use without any serious interruption since 1864. It is erected on a wooden framework on the tower of the observatory house and the following information concerning it, is taken from the introduction to the volume containing the results of the Meteorological Observations during 1861-1890 published in 1892. "The cups of the anemograph are about 8½ inches in diameter and the distance from centre to centre of opposite cups is 4 feet. The height of the cups above the ground is 44 feet and the height above the parapet of the building is 18 feet. I can find

no record of any tests that were made as to the accuracy of the scale of this instrument but as it was made under the direction of the late Professor Balfour Stewart it is probable that due care was taken regarding this important point. The readings for wind velocity have been accepted without any correction and the instrument has been taken as the standard for smaller instruments throughout the Presidency. The accuracy as regards wind direction has been tested from time to time. The record of direction is not thoroughly satisfactory when the velocity falls below two miles an hour". In its present state the instrument seems to be working satisfactorily. Having been in continued use for so many years the gearing is a good deal worn and it would be justifiable to suspect some change in the scale. Comparisons made with a Dines' Pressure Gauge Anemometer have however shown that no serious change has taken place if we assume that the scale was correct when the instrument was first set up. As far as the instrument itself is concerned then, its records during recent years appear to be directly comparable without sensible reductions with its earlier records.

The exposure has changed.

4. On the other hand considerations advanced in section 7 prove clearly that changes have taken place in the surroundings which have materially affected the total amount of movement recorded by the anemometer. The direction of the movement at the vane has not been interfered with; this is proved by a comparison of the results given in the two volumes referred to in section 1 and those obtained here. It is possible to allow for the effect of these changes with considerable certainty and thus to render the whole series of records taken by means of the instrument homogeneous and directly comparable with one another. The results so obtained may be regarded as truly indicating an important part of the wind system of southern India, directly related to the general temperature and pressure conditions and practically free from local influences such as would be impressed on the movement by some dominating feature in the configuration of the neighbouring surrounding country, as for example the Western Ghâts on the west coast or the hills to the east of Chittagong.

Method of recording, &c.

5. The air movement and direction are continuously recorded on a plain sheet of "metallic" paper laid round a cylinder. This cylinder is controlled by a clock and makes one revolution in 24 hours. The sheet is changed at 8 A. M. every day. It has been the custom to mark each sheet at some specified hour during the 24 hours it is receiving the record, and this is generally done at 8 P. M. Any serious irregularity in the driving is thus detected and may be allowed for in dividing up the trace into hourly intervals. The air movement for each hour is read off to the nearest mile and it is entered with the direction for that hour on a prepared form. One of these forms is sufficient for the hourly records for half a month together with the corresponding hourly rainfall and some other classified data of wind and rainfall. These numerical data were utilised directly, and it was not necessary except in cases of doubt to refer to the tracings on the anemograph sheets. The records available extend over a period of 40 years.

Data used in discussion.

6. It was not found practicable to utilise the whole of this material in the present discussion. In deciding what portion should be selected it was borne in mind, (1)

that the instrument should have been at work for a sufficient time before the period selected so as to have settled down to the steady state, (2) that the period should be continuous and long enough to deduce satisfactory means from which normal values could be caculated. Accordingly I selected the records during the years 1865-75 inclusive. The instrument had been at work for a sufficient time before the beginning of this period, it was thought, to have settled down to a steady state, and the period appeared long enough to satisfy the second consideration.

Evidence of change.

7. The following table gives the mean daily air movement in miles at Madras for each year from 1865 to 1904 inclusive :—

TABLE I.

Year.	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	Means.
Daily air movement.	177	193	184	182	194	174	178	177	178	168	171	180

Year.	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	Means.
Daily air movement.	179	188	161	175	157	170	175	178	176	165	143	170

Year.	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	Mean.
Daily air movement.	166	160	148	144	179	157	154	158	152	154	158	156

Year.	1898	1899	1900	1901	1902	1903	1904	...	...	...	Mean.
Daily air movement ...	151	152	161	159	161	143	166	...	...	...	156

The data given in the above table show clearly that there has been a progressive diminution in the recorded air movement, the mean daily movement for the first series of eleven years, being 180 miles, for the second series, 170 miles, and for the third series, 156 miles. The results obtained from these by taking three year means are plotted in Plate I fig 1. and from this it is clear that the decrease was almost continuous up to 1887 and has since practically ceased. It has already been stated that recent comparisons with a Dines' Pressure Gauge Anemometer have shown that the scale of the instrument is correct. The position of the anemometer at Madras has never been changed nor have any structural alterations been made in the building on which it is placed, that could possibly affect the exposure. Moreover alterations of this kind

would show their effects by a sudden and constant change and not by a persistent progressive one of the kind shown here between 1865 and 1887. Hence some slow change must have taken place in the surroundings which continuously and increasingly affected the flow of air passing the anemometer. Owing to this the data require reduction before the velocities in different years from 1865 to 1887 can be compared. If we assume that the change has taken place uniformly (and Plate I fig. 1 shows that to be very nearly the case) all the velocities for the year 1865, for instance, require to be reduced in value by about 2½ per cent. and all the velocities for 1875 to be increased by about 2½ per cent. to make them strictly comparable with one another; for intermediate years the corrections to be applied will be proportionately less. The wind velocities are however only read to the nearest mile on the sheets (see section 5) and corrections of this magnitude are insignificant except when the velocity exceeds 20 miles an hour. Such corrections would not of course affect the mean values which have been obtained and are used in the following discussion: these have been deduced from the data without applying any correction, and it is to be noticed that the mean values deduced show no hourly movement appreciably greater than 14 miles, a value considerably less than that for which the correction becomes appreciable.

Cause of the change.

8. As to the cause of this steady diminution in velocity, it seems most probable that the greater part, if not the whole of it, is to be ascribed to the change produced by growing trees. This explanation suggested itself to me on seeing an old drawing of the observatory, where it was shown that the whole neighbourhood was then open and almost entirely free from trees to a considerable distance from the observatory. Even at present there are no trees very near and none overtop the instrument, but there can be no doubt that those in the neighbourhood do exercise a considerable influence on the air movement at the cups of the anemometer. Many of them were planted in the earlier part of the century and have now attained their full growth. They have at any rate completely altered the character of the surroundings of the observatory and materially lowered the effective height of the anemometer, and this action was increasing for some time after the installation of the Beckley. Some support is given to this inference by comparing the air movements at the observatory and at the harbour where the exposure of the anemometer is free and unobstructed on the east, the sea, side. The velocities at the harbour are as a rule considerably higher than those recorded at the observatory at the same time especially when the wind blows from the sea side. Special tests and comparisons have shown that these differences are not due to the instruments themselves and consequently they must be largely due to differences in the surroundings.

Tables described.

9. The means contained in the following tables are obtained from the records of the eleven years 1865-1875. Table II gives the mean hourly movement of air, irrespective of direction, for each hour of the mean day of each month and also of the year, and the hourly variations of these from the daily means.

Table III.—Constants of the periodical formula (I) for the diurnal variation of the air movement, irrespective of direction, at Madras; computed from Table II.

Month.	p_1.	q_1.	p_2.	q_2.	p_3.	q_3.	p_4.	q_4.
January	−3·606	−1·932	1·083	0·480	0·076	0·113	−0·358	−0·291
February . . .	−5·383	−2·201	0·755	0·541	0·114	0·030	−0·309	−0·192
March	−3·954	−2·450	0·855	0·367	0·235	−0·049	−0·390	−0·132
April	−4·497	−2·657	0·992	−0·026	0·386	−0·127	−0·297	0·093
May	−2·317	−1·517	0·545	−0·047	0·402	−0·288	−0·222	0·271
June	−2·364	−0·514	0·897	−0·274	0·301	0·256	−0·416	0·090
July	−2·214	−0·397	1·104	−0·415	0·159	0·315	−0·383	0·010
August . . .	−1·668	−0·050	1·251	−0·133	0·269	0·113	−0·298	−0·066
September . . .	−2·098	0·461	0·955	0·001	0·335	0·137	−0·363	0·059
October . . .	−2·674	−0·631	0·715	0·495	0·201	−0·079	−0·323	0·043
November . . .	−3·277	−1·208	0·978	0·330	−0·005	0·027	−0·330	−0·110
December . . .	−3·979	−1·631	1·316	0·226	0·062	0·096	−0·418	−0·185
YEAR .	−3·003	−1·229	0·955	0·128	0·211	0·045	−0·342	−0·033

Table IV.—Constants of the formula (II) computed from Table III.

Month.	U_1.	u_1.	U_2.	u_2.	U_3.	u_3.	U_4.	u_4.
		° ′		° ′		° ′		° ′
January . . .	4·091	242 49	1·184	66 6	0·137	34 32	0·461	230 54
February . . .	4·040	236 52	0·929	54 23	0·118	75 16	0·364	238 9
March . . .	4·652	238 13	0·931	66 46	0·240	101 47	0·412	251 18
April	5·224	239 25	0·992	91 30	0·406	108 13	0·311	287 23
May	2·770	236 47	0·547	94 56	0·494	125 37	0·351	320 41
June	2·419	257 44	0·938	106 59	0·395	49 37	0·426	282 13
July	2·249	259 50	1·179	110 36	0·353	26 47	0·383	271 30
August . . .	1·669	267 57	1·258	96 10	0·291	67 13	0·305	257 31
September . . .	2·148	282 24	0·955	89 56	0·362	67 45	0·368	279 14
October . . .	2·748	256 43	0·870	55 18	0·216	111 27	0·326	277 35
November . . .	3·493	249 46	1·032	71 21	0·027	349 30	0·348	251 34
December . . .	4·300	247 43	1·335	80 15	0·114	32 51	0·457	246 8
YEAR .	3·244	247 45	0·963	82 22	0·216	77 52	0·344	264 29

Table V—Shewing mean hourly air movement, irrespective of direction, computed from the constants given in Table IV.

Hour.	January.	February.	March	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
Midnight	—2·81	—2·82	—3·29	—3·43	—1·59	—1·57	—1·31	—0·44	—1·18	—2·07	—2·63	—3·02	—2·18
1	—3·10	—3·16	—3·71	—4·10	—1·98	—1·51	—1·34	—0·55	—0·87	—1·92	—2·70	—3·27	—2·37
2	—3·09	—3·16	—3·87	—4·65	—2·48	—1·55	—1·42	—0·77	—0·73	—1·73	—2·57	—3·27	—2·42
3	—3·06	—3·17	—3·98	—5·18	—3·04	—1·97	—1·77	—1·17	—0·97	—1·72	—2·49	—3·29	—2·64
4	—3·15	—3·31	—4·12	—5·40	—3·30	—2·47	—2·34	—1·69	—1·33	—1·88	—2·62	—3·56	—2·94
5	—3·58	—3·41	—4·14	—5·02	—2·98	—2·70	—2·65	—1·97	—1·49	—1·96	—2·77	—3·79	—3·04
6	—3·47	—3·31	—3·63	—3·84	—2·01	—2·08	—2·19	—1·72	—0·98	—1·59	—2·53	—3·46	—2·56
7	—2·56	—2·43	—2·35	—1·96	—0·71	—0·63	—0·85	—0·75	0·17	—0·71	—1·61	—2·19	—1·38
8	—0·83	—0·95	—0·58	0·08	0·35	1·12	0·93	0·63	1·53	0·40	—0·11	—0·16	0·30
9	1·19	0·71	1·18	1·83	0·91	2·38	2·39	1·85	2·50	1·35	2·48	1·96	1·64
10	2·83	2·08	2·57	3·05	1·16	2·85	3·12	2·51	2·80	1·98	2·72	3·56	2·60
11	3·76	3·04	3·46	3·94	1·50	2·74	3·11	2·52	2·61	2·39	3·46	4·12	3·07
Noon	5·24	3·72	4·17	4·81	2·25	2·55	2·78	2·34	2·37	2·87	3·91	4·82	3·40
13	4·60	4·36	4·93	5·66	3·12	2·53	2·48	2·17	2·27	3·38	4·20	5·03	3·75
14	4·87	4·84	5·53	6·05	3·62	2·55	2·20	1·97	2·15	3·71	4·25	5·07	3·88
15	4·78	4·87	5·30	5·72	3·38	2·25	1·69	1·49	1·69	3·36	3·81	4·59	3·58
16	3·84	4·13	4·54	4·50	2·44	1·38	0·83	0·63	0·66	2·28	2·74	3·38	2·60
17	2·32	2·74	2·88	2·82	1·32	0·30	—0·07	—0·45	—0·63	0·82	1·31	1·63	1·24
18	0·59	1·17	1·19	1·26	0·47	—0·54	—0·77	—1·38	—1·64	—0·49	—0·07	—0·02	—0·02
19	—0·66	—0·05	—0·11	0·12	0·03	—0·91	—1·01	—1·71	—2·09	—1·27	—0·93	—1·05	—0·80
20	—1·23	—0·77	—0·76	—0·56	—0·13	—0·96	—0·91	—1·57	—2·03	—1·58	—1·29	—1·44	—1·10
21	—1·43	—1·17	—1·14	—1·17	—0·37	—1·01	—0·79	—0·97	—1·78	—1·71	—1·48	—1·58	—1·22
22	—1·71	—1·62	—1·75	—1·87	—0·78	—1·23	—0·94	—0·61	—1·84	—1·86	—1·80	—1·90	—1·46
23	—2·22	—2·24	—2·52	—2·66	—1·20	—1·50	—1·29	—0·50	—1·41	—2·05	—2·28	—2·46	—1·83

Tables III and IV give the constants of the periodic formulae representing the diurnal variations shown in Table II.

Table V shows the values calculated by the help of the periodic formulae whose constants are given in Table IV. These may be regarded as normal values.

Some of the values given in Table II are plotted on Plate II in order to show graphically how the total air movement varies throughout the day at different periods of the year.

Methods employed.

10. The direction of the air movement at Madras varies during the day, especially from May to October. Hence to find the mean air movement in direction as well as magnitude for each hour of the mean day of any month it is necessary to take into account the direction and the magnitude of the movement recorded. This has been done in obtaining the values given in Tables IX and XIII which are discussed later on. For the present we shall consider and discuss the results given in Table II. To prevent misunderstanding it would be well to state here what the air movement is which is entered against each hour in Tables II and V and similar subsequent tables. The system that has been adopted is the following:—

Against the hour 0 the movement between midnight and 1 A.M. is entered.

Against hour 1 the movement between 1 A.M. and 2 A.M. is entered.

Thus the value against any hour h, say, is the air movement between the hours h and h+1; this may be regarded as the velocity at the hour $h+\frac{1}{2}$. These facts must be borne in mind in deducing any conclusions from the tables and the diagrams, *e.g.*, the times of maxima, minima, etc.

Annual variation

11. The mean hourly air movement for each month deduced from the data in Table II are given in the bottom line of that table and are reproduced here for convenience.

Month	Jan.	Feb.	March.	April	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Hourly velocity.	6·36	5·51	6·58	5·39	10·03	9·89	8·81	7·64	6·93	5·19	7·24	7·58	7·51

These values are plotted in Figure 3 (*a*) Plate I. The length of each month is taken to be the same in this figure; this does not introduce any confusion in the interpretation of the curve.

The abscissæ of the points represent the intervals between January first and the middles of the several months and the ordinates are the corresponding values of the mean hourly air movement for the mean day of the respective months. Through the points thus laid out a free-hand curve is drawn which shows at a glance the principal and larger variations in the mean air movement throughout the year. The movement varies considerably in strength and has two well defined maxima and two minima.

The dates of these estimated from the curve in figure 3, Plate I are given here.

1st Minimum 14th February.	1st Maximum 25th May.
2nd Minimum 15th October.	2nd Maximum 4th December.

These results are deduced from the mean values obtained from the recorded velocities without taking into account their directions. It is interesting to see how they compare with the variations shown in the mean values obtained by resolving each hourly movement into its two components southerly and westerly. These are given in Tables IX and XIII; the resultants of the mean southerly and westerly component for each month are shown in figure 2, Plate I, and their magnitudes are :—

Month.	Jan.	Feb.	March	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Hourly velocity	5·94	5·76	5·60	7·79	7·47	5·01	5·42	4·38	5·54	0·78	5·66	6·77

These are plotted in figure 3, Plate I and a free hand curve drawn through them exactly as in the preceding case. The two curves are very similar to one another and are almost parallel throughout. Both have two well defined maxima and minima and the dates of the minima are identical in both, *viz.*, 14th February and 15th October. The dates of the maxima estimated from these results are slightly different from those previously obtained. They are

1st Maximum, 7th May or a fortnight earlier }
2nd Maximum, 14th December or 10 days later } than the dates given above. They

are sufficiently close however to show that the main features of the annual variations of the air movement, regarded from two different points of view are very similar and the times of maxima and minima are almost identical in both.

Comparison with resultant velocities.

12. The values of the air movement deduced by the second method are of necessity smaller than the values obtained when no account is taken of direction. In obtaining the latter only the magnitude of the velocity is taken into account and winds even from opposite quarters are added together; whereas in obtaining the former such winds would cancel each other and would contribute nothing to the total from which the mean is deduced. This accounts for the very great difference between the two values for the month of October. For during this month the wind shifts in the course of a few days from a direction approximately southwest to a north easterly direction. The following data from "Madras Observatory Meteorological Means" illustrate this point and will be referred to more fully hereafter :—

	September.			October.											
Date	15	25	30	4	5	6	7	8	9	10	11	12	14	16	20
Direction of wind	19	18	17	16½	15½	14	13	12	10	9	8	7	6	5	4

It must be remembered that this table gives the mean wind directions deduced from 30 years' observations between 1860 and 1890 embodying weather conditions of very different kinds. The wind directions are numbered from 0 to 32 according to the points of the compass from which they blow.

Examination of the records for any one year reveals the fact that the shift of wind from southwest to northeast occurs in a few days or even hours and that the transition is much quicker than would be inferred from an examination of the above means. Large differences in the values obtained from the two methods are also observable for May and the whole of the southwest monsoon period June—September. It is sufficient to remark here that this difference also is due to the large change in the direction of the wind that occurs during the day throughout this period. Inspection of Plates V and VI, where the magnitude and direction of the mean hourly wind velocities for each month deduced from the data in Tables IX and XIII are plotted, will show the large daily change in direction that takes place in these months—the longest diameter of the variation curve being almost at right angles to the direction of the resultant. For November, December, January and up to April the difference is much smaller. In these months the daily change in direction is small and the longest diameter of the variation curve is nearly parallel to the direction of the resultant.

Annual variation.

13. The chief features of the mean monthly air movement (calculated irrespective of direction) at Madras during the year are :—

(*a*) Two well defined maxima and minima the dates of which are : 1st Minimum 14th February, 1st Maximum 25th May, 2nd Minimum 15th October, 2nd Maximum 4th December.

(*b*) A nearly uniform increase from the 14th February to the 25th May, *i.e.*, during the hot weather period.

(*c*) A more or less uniform decrease from the 25th May to 15th October, *i.e.*, approximately during the southwest monsoon period.

(*d*) A nearly uniform increase from the 15th October to 4th December, *i.e.*, during the transition period approximately—the period between the withdrawal of the southwest monsoon from Bengal and about a fortnight before its retreat and final withdrawal from the south of the Bay and the establishment of the northeast monsoon throughout.

(*e*) A nearly uniform decrease from 4th December to the 15th February, *i.e.*, approximately during the cold weather period.

These conclusions are of great interest and emphasise the remarkable simplicity of the wind system at Madras in its broader features. The air movement is closely related to the season of the year and on the average either increases continuously or decreases continuously throughout nearly the whole of the season. The times of maxima and minima coincide very nearly with the dates which mark the commencement and end of the four seasons in southern India.

It must be remembered that the curve in Fig. 3, Plate I does not show all the variations in the mean daily movement throughout the year but only the larger variations. The ordinates represent the means of observations extending over a month of time. Hence fluctuations of a period less than a month are smoothed out.

Temperature and Pressure.

14. In order to trace the relations between the air movement at Madras and the general temperature and pressure conditions over the Peninsula and neighbouring sea areas it is necessary to realise what these conditions actually are, and to consider how they change in the course of the day and the year. It is not however necessary to enter into a lengthy and detailed preliminary account of these conditions in this paper.

Reference should be made to the maps in Sir John Eliot's Climatological Atlas of India where temperature and pressure distributions at three important epochs in the day in each month can be seen at a glance, and the manner in which they vary from month to month in the course of the year. These maps will show in a more vivid manner than any description can, the general meteorological conditions to which we shall refer as briefly as possible from time to time in the present discussion.

Air movement in hot weather.

15. The air movement is *most vigorous* at Madras during the last week in May and another maximum occurs in December. These conclusions agree with those deduced from the mean daily wind velocities given in the Madras Meteorological Means which were obtained from data extending from 1860 to 1890. The date of the May maximum coincides with that of the hottest period in Madras. The following table confirms this point.

	May.						June.		
Date.	16	20	23	26	28	31	3	6	9
Maximum temperature ...	98·0	98·4	97·1	97·6	99·7	99·5	99·2	98·7	98·6
Minimum temperature ...	80·7	80·9	81·2	81·5	81·5	81·1	81·0	81·0	80·8

It has already been remarked that the air movement increases nearly uniformly during the period 14th February to the end of May.

During the first part of this period temperature increases rapidly in the interior and more slowly on the Madras coast. By the end of April it has reached its maximum at such stations as Bellary, Coimbatore, Salem and Trichinopoly, and the hottest area at this time includes the Ceded Districts and Deccan. During May temperature falls slightly over the southern and western half of the Peninsula but continues to increase on the Madras coast, the Circars and to the north of these areas. Thus during this period of the year the hottest area increases in intensity and gradually extends and shifts its position from the Ceded Districts to a more northerly and easterly position. With these temperature changes simultaneous large changes take place in the pressure distribution, the

area of lowest pressure coinciding roughly with the area of highest temperature. Over the surrounding sea areas the temperature changes are small (see section 22) as far as can be inferred, and during May the Peninsula is hotter both by night and day than these sea areas. Conditions like these give rise to an indraught from the surrounding sea areas towards the hot low pressure area in the interior, the movement increasing in intensity with the increasing differences in temperature and consequent deepening of the low pressure area. Thus the increase in vigour of the air movement observed at Madras during the period from the middle of February to the end of May, is to be ascribed to the increasing temperature of the hot area in the interior and the movement of the air from the surrounding areas over a surface which becomes during the season increasingly warmer than the air.

It is worthy of remark that the winds are (on the average) stronger at Madras at the height of the hot weather than they are during the southwest monsoon or at any other time of the year. This appears to be also the case at many other places in India. On the Bengal coast for instance the sea winds in May are on the average stronger than the southwost monsoon winds of June, July and August.

During southwest monsoon.

16. During the period from the May maximum to the October minimum the wind at Madras may be roughly ascribed to two causes (1) the movement due to the southwest monsoon current (2) the part due to causes more local in character such as temperature differences and the movement of the air over a surface warmer than itself. The first is nearly constant during the first part of this interval but diminishes later on and disappears by the end of September and the beginning of October. The second part diminishes with the temperature differences over the province, which themselves become smaller as the season advances.

Table VI confirms this point.

TABLE VI.—Showing normal maximum and minimum temperatures at certain stations in southern India.

Station.	Temperature.	January.			February.			March.			April.			May.			June.		
		10	20	30	10	20	28	10	20	30	10	20	30	10	20	30	10	20	30
Bellary	Maximum	86·5	87·4	90·3	93·0	95·2	98·1	98·9	100·4	103·3	103·7	104·3	104·8	103·1	101·6	99·3	94·3	95·1	92·1
	Minimum	59·5	60·5	61·4	63·5	66·0	68·7	69·7	72·6	75·1	76·9	77·4	78·1	77·5	76·6	76·6	75·7	75·4	74·9
Nellore	Maximum	84·9	86·0	88·2	89·1	92·3	92·7	93·8	96·0	99·4	100·5	101·0	103·6	107·0	105·2	106·3	101·3	100·7	100·1
	Minimum	66·2	65·9	66·5	68·4	69·6	70·1	71·6	72·2	74·9	77·1	77·8	80·8	81·9	82·4	84·0	81·0	81·4	81·3
Bangalore	Maximum	78·5	79·6	81·9	84·3	86·2	88·3	89·2	90·1	92·7	93·3	93·5	93·6	92·1	90·3	87·9	83·8	84·9	83·3
	Minimum	55·6	57·0	57·5	57·6	60·0	60·9	63·2	65·2	67·1	68·6	69·9	70·4	69·6	68·5	67·7	66·5	66·2	66·0
Madras	Maximum	84·3	84·6	85·3	86·2	87·0	87·8	88·3	89·6	90·8	92·4	92·9	95·3	97·0	98·4	97·6	98·6	97·9	97·4
	Minimum	67·6	67·4	67·1	67·5	68·4	69·1	70·9	72·8	74·9	76·5	77·7	79·4	80·6	80·9	81·2	80·7	79·9	79·5
Salem	Maximum	87·5	88·3	90·5	92·3	94·4	96·9	97·2	98·0	100·7	101·1	101·1	101·5	99·9	97·3	96·6	93·3	91·3	92·9
	Minimum	62·4	63·6	64·2	63·6	65·6	66·8	69·5	71·8	73·6	75·6	76·1	76·3	76·0	74·6	75·0	73·4	73·5	72·6
Cuddalore	Maximum	82·8	83·3	84·2	84·9	86·5	87·3	88·1	89·4	91·6	92·3	92·7	95·9	99·7	99·5	99·9	98·2	97·3	...
	Minimum	67·5	67·4	66·6	68·7	69·5	70·0	71·6	72·3	74·8	76·9	77·3	79·4	80·3	80·9	80·9	79·9	79·7	...
Coimbatore	Maximum	85·8	86·8	89·2	91·1	93·4	95·4	95·4	96·0	98·0	98·6	97·9	98·1	95·8	93·6	92·7	89·4	89·8	88·7
	Minimum	63·6	64·1	64·4	63·6	66·0	66·9	68·4	71·4	72·0	73·4	74·1	74·0	73·8	73·0	72·9	71·4	71·3	71·0
Trichinopoly	Maximum	86·4	87·5	89·6	90·6	93·0	95·5	95·9	97·3	100·2	101·4	101·5	101·7	101·4	100·7	99·9	98·0	99·0	97·0
	Minimum	66·2	67·3	67·2	66·6	68·8	69·8	70·9	73·7	75·6	77·2	78·1	78·4	78·7	77·4	78·3	77·8	77·9	77·6
Negapatam	Maximum	81·3	81·9	82·7	83·4	84·9	86·4	87·4	89·0	91·1	92·3	93·0	93·9	94·7	93·2	97·4	95·4	96·7	95·6
	Minimum	70·5	71·1	70·0	70·4	72·3	72·6	74·7	76·4	77·9	78·6	79·2	79·5	82·1	79·2	82·1	79·1	78·6	77·6

TABLE VI.—Showing normal maximum and minimum temperatures at certain stations in southern India—concld.

Station.	Temperature.	July.			August.			September.			October.			November.			December.		
		10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30
Bellary	Maximum	91.0	90.5	91.2	91.4	90.4	90.8	90.5	90.4	90.1	90.2	88.9	87.6	86.8	86.1	85.2	85.4	84.4	85.8
	Minimum	74.6	74.2	73.9	73.7	72.9	73.2	72.7	73.0	72.8	71.8	70.4	69.1	66.9	64.7	62.2	61.1	60.7	59.4
Nellore	Maximum	95.9	95.8	95.7	95.4	91.8	94.2	93.2	93.9	93.1	93.3	89.9	88.4	87.1	86.2	84.9	84.4	84.1	84.8
	Minimum	79.4	78.9	78.8	78.3	78.2	78.1	77.1	76.7	77.4	76.4	75.7	73.9	74.9	70.8	70.1	67.9	65.8	67.9
Bangalore	Maximum	81.4	82.0	81.7	81.6	81.7	81.5	81.3	81.8	82.7	81.3	80.8	79.0	79.2	77.8	77.8	77.5	76.6	77.2
	Minimum	65.8	65.8	65.2	65.6	65.5	65.8	65.2	64.4	65.7	65.1	64.7	64.1	63.9	60.4	59.9	58.9	58.4	57.0
Madras	Maximum	95.6	95.4	94.6	93.5	94.1	92.9	93.4	93.4	92.4	90.2	87.6	86.6	85.8	84.4	83.2	83.9	83.4	83.6
	Minimum	78.5	78.5	77.6	77.5	77.4	76.9	77.3	77.3	76.6	75.9	74.8	73.6	73.0	71.6	71.1	70.9	69.5	68.3
Salem	Maximum	92.3	92.3	93.0	91.4	91.3	90.9	90.4	92.1	91.7	90.2	88.7	87.5	86.8	87.4	86.3	86.5	84.4	86.2
	Minimum	72.3	72.3	72.1	71.8	72.1	71.9	71.0	71.1	71.9	70.9	70.1	69.6	69.3	67.1	65.7	65.4	65.3	63.4
Cuddalore	Maximum	94.9	91.9	91.6	93.6	93.3	92.3	92.6	91.9	89.2	89.1	88.3	86.0	85.9	84.5	84.1	82.7	82.6	82.6
	Minimum	78.0	77.7	77.5	76.8	76.6	75.9	76.0	75.9	75.0	74.8	74.7	73.2	72.9	70.8	71.1	68.8	69.9	69.4
Coimbatore	Maximum	87.7	87.7	88.0	87.9	89.1	88.7	89.3	90.0	89.9	88.9	87.7	86.4	85.8	86.4	85.2	85.0	83.2	84.9
	Minimum	70.8	70.7	70.5	70.5	70.4	70.7	70.6	70.5	70.5	70.7	70.6	70.4	70.1	68.4	67.2	66.7	66.1	64.9
Trichinopoly	Maximum	96.6	96.7	97.3	95.7	96.6	94.9	94.5	96.1	94.5	92.8	89.7	87.9	86.4	87.6	85.3	84.7	83.6	85.0
	Minimum	77.3	77.4	77.0	76.2	76.6	75.6	75.3	75.8	75.1	74.6	73.7	72.8	72.9	70.7	69.9	69.1	69.0	67.8
Negapatam	Maximum	94.8	94.5	94.7	92.8	92.1	92.4	91.4	92.8	91.4	89.4	86.7	85.1	83.7	84.0	81.8	81.3	80.2	80.7
	Minimum	77.5	77.9	77.3	77.0	76.7	76.6	76.1	76.4	76.1	76.4	75.5	74.6	75.0	73.2	72.3	71.8	71.7	71.5

During the hot weather, as has already been stated, the air movement appears to be almost entirely due to the second of these causes. Eliot has already stated (India Met. Memoirs Volume VI, Part VI, page 487) that the weather in India during the hot weather period is less related to the meteorology of the neighbouring countries and seas than in any other period of the year.

During the transition period.

17. The air movement is *least vigorous* at Madras during the second week in October—the commencement of the transition period. At this time pressure as a rule is very uniform over the Presidency and the Bay, and the southwest monsoon movement across the Peninsula has ceased. What air movement there is appears to be local in character and arises from temperature differences which, at this season of the year, are also very small. From the middle of October to the middle of December the air movement increases. During this period the observed movement, which is generally from the north-east, may be due to winds of continental origin—the northeast monsoon proper—or to winds of oceanic origin—the southwest monsoon winds—which generally continue to blow into the Bay throughout this period. These often recurve through south and east round a depression in the Bay and appear on the Madras coast as northerly or north-easterly winds. In the first case fine dry weather, with clear days and cool nights, prevail at Madras and over the greater part of the Presidency. Gradients for northerly winds obtain over the Peninsula and the Bay and the area of lowest pressure is in the south-east of the Bay. In the second case a depression forms in the south or southwest of the Bay which is effective in bringing the moist southwest monsoon winds on to the Madras coast from a northeasterly direction. Under these circumstances cloudy rainy weather prevails over the south of the Peninsula and generally moderate to heavy rain falls, especially on the Madras coast. This is popularly known as the "northeast monsoon". The inoursion of the southwest monsoon winds into the Bay diminishes, but in a very irregular manner, from October to December, and generally about the third week of the last month of the year they retreat altogether and the northeast monsoon winds and fine weather prevail throughout. Thus the period of gradually increasing air movement from 15th October to 4th December observed at Madras is the period of the retreat of the southwest monsoon and gradual establishment of the northeast monsoon over southern India and the Bay, with steeper gradients.

During the cold weather.

18. The fourth period extends from the middle of December to the middle of February and is characterised by fine dry weather, warm days and cold nights. Pressure becomes more uniform over India during this period and the movement becomes less vigorous in consequence. During these two periods the hottest area is in the south of the Presidency. It appears to be too small in extent and too deficient in vigour to affect to any considerable extent the mean air movement at Madras during the season, though the daily variations are large.

Diurnal variations.

19. The data of the diurnal variations are given in Table II and some of them are plotted in Plate II.

The values calculated from the formulæ whose constants are given in Tables III and IV are tabulated in Table V. The variations shown in Tables II and V agree closely with one another.

The mean differences between them irrespective of sign, are given for each month and year in the following form :—

Month.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Year.
Difference between calculated and observed values.	0·15	0·12	0·13	0·25	0·17	0·08	0·11	0·09	0·13	0·09	0·10	0·13	0·07

The greatest differences between the calculated and observed values in each month and the year are as follows :—

Month.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Year.
Greatest difference.	0·35	0·31	0·41	0·65	0·50	0·27	0·35	0·26	0·29	0·20	0·34	0·20	0·23

The differences in no case except April exceed half a mile an hour and the formulæ may thus be taken to represent with fair accuracy the diurnal variation in the air movement, and to furnish satisfactory normal values.

The formulæ.

20. An examination of the constants in Table IV shows that the greater part of the daily variation in the air movement is of a diurnal character, the constant U_1 being in nearly all months much greater than U_2 or any of the other constants. The following table show the ratio of U_1 to U_2 for each month and for the whole year.

Month.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Year.
Ratio $\frac{U_1}{U_2}$.	3·3	4·3	5·0	5·3	5·0	2·6	1·9	1·3	2·75	3·2	3·1	3·2	3·4

The changes in the value of the ratio $\frac{U_1}{U_2}$ are almost entirely due to alteration in the value of U_1, U_2 being nearly the same for all months except in May when its value is about half the average values for the other months. The epoch of the first component u_1, whose amplitude is U_1, varies slightly from month to month, but remains in the same quadrant, throughout the year except in September. The epoch of the second component u_2 is in the first quadrant from October to March and in the second quadrant from April to September. The first of these periods includes the transition period and the cold weather, the second includes the hot weather and southwest monsoon. The variation from the mean of the epoch u_2 throughout the year is as follows :—

Month.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	
Variation from mean.	10°	15°	14°	12°	15°	−7°	−8°	−16°	−30°	−5°	2°	4°	

Thus during the period June to October when the observed air movement is largely due to the southwest monsoon the epoch u,, is on one side of its mean value throughout while during the remaining period of the year, comprising the cold weather and hot weather periods, it is on the other side of the mean. It does not seem possible however to ascribe every one of these components into which the daily variations in air movement have been resolved to a distinct physical cause, and they are not discussed further.

Character of diurnal variations.

21. The curves in Plate II, showing the daily variations in the air movement exhibit a general resemblance to the curves showing the daily variations in air temperature.

The following features are common to the two sets of curves :

(i) A rapid increase in the values of the ordinates from the minimum soon after sunrise to nearly the maximum.

(ii) A rapid fall till sunset, followed by

(iii) A less rapid and gradually diminishing fall to the minimum shortly after sunrise the following day (except in August and September).

Table VII shows the ratios of the mean movement for each hour of the day to the mean hourly movement for the whole day in each month.

TABLE VII.

Hour.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Year.
Midnight.	0·6	0·5	0·5	0·6	0·8	0·8	0·9	0·9	0·8	0·6	0·7	0·6	0·7
1	0·5	0·5	0·4	0·5	0·8	0·9	0·9	0·9	0·9	0·6	0·6	0·6	0·7
2	0·5	0·4	0·4	0·4	0·7	0·8	0·8	0·9	0·9	0·7	0·6	0·5	0·7
3	0·5	0·4	0·4	0·4	0·7	0·8	0·8	0·8	0·9	0·7	0·7	0·5	0·6
4	0·5	0·4	0·4	0·4	0·7	0·8	0·8	0·8	0·8	0·6	0·6	0·5	0·6
5	0·5	0·4	0·4	0·4	0·7	0·7	0·7	0·7	0·8	0·6	0·6	0·5	0·6
6	0·5	0·4	0·4	0·5	0·7	0·8	0·7	0·7	0·8	0·7	0·6	0·5	0·6
7	0·5	0·5	0·6	0·8	1·0	0·9	0·9	0·9	1·0	0·9	0·8	0·7	0·8
8	0·9	0·8	1·0	1·1	1·1	1·1	1·1	1·1	1·2	1·1	1·0	1·0	1·0
9	1·2	1·2	1·2	1·2	1·1	1·2	1·3	1·2	1·4	1·2	1·2	1·3	1·2
10	1·5	1·4	1·3	1·3	1·1	1·3	1·3	1·3	1·4	1·4	1·4	1·5	1·3
11	1·6	1·5	1·5	1·5	1·2	1·3	1·4	1·2	1·4	1·5	1·5	1·6	1·4
Noon.	1·6	1·7	1·7	1·6	1·2	1·2	1·3	1·3	1·3	1·6	1·5	1·6	1·4
13	1·7	1·8	1·8	1·7	1·3	1·3	1·3	1·3	1·3	1·7	1·6	1·7	1·3
14	1·7	1·8	1·8	1·7	1·3	1·3	1·2	1·3	1·3	1·7	1·6	1·6	1·5
15	1·7	1·8	1·8	1·7	1·3	1·2	1·2	1·2	1·2	1·6	1·6	1·6	1·3
16	1·6	1·8	1·7	1·6	1·2	1·1	1·1	1·1	1·1	1·5	1·4	1·5	1·4
17	1·4	1·5	1·5	1·4	1·2	1·0	1·0	1·0	0·9	1·1	1·1	1·2	1·2
18	1·0	1·2	1·1	1·1	1·0	1·0	0·9	0·8	0·7	0·9	1·0	1·0	1·0
19	0·9	1·0	1·0	1·0	1·0	0·9	0·9	0·8	0·7	0·8	0·9	0·9	0·9
20	0·8	0·9	0·9	0·9	1·0	0·9	0·9	0·8	0·7	0·7	0·8	0·8	0·9
21	0·8	0·8	0·8	0·9	1·0	0·9	0·9	0·9	0·7	0·7	0·8	0·8	0·8
22	0·7	0·7	0·7	0·8	0·9	0·9	0·9	0·9	0·8	0·8	0·7	0·7	0·8
23	0·6	0·5	0·6	0·7	0·9	0·9	0·9	0·9	0·8	0·8	0·7	0·7	0·8

This Table and Table II show that the daily variations are smaller, both absolutely and relatively to the mean, in the months May to September than in the months November to April.

We must now examine the causes that bring about these daily variations, and see if the observed meteorological conditions and their diurnal changes are sufficient to account for the differences noted above.

Cause of differences.

22. From the middle of October to the end of May the mean direction of the wind at Madras is from the sea. At the beginning and the end of this period however the direction changes rather rapidly and hence it is only from about the beginning of November to the middle of May that steady sea winds are fully established and persistently prevail. The temperature of the air over the sea is subjected to two periodic variations (i) An annual oscillation, (ii) a diurnal oscillation. Within the tropics the extreme variation of the annual oscillation probably does not exceed 6° F. and that of the daily oscillation 3° or 4° F., while the mean temperature for the year does not materially differ from 80° F. in all probability. In the Bay of Bengal the maximum temperature of the air on the sea surface occurs in May or the beginning of June just before the arrival of the monsoon and the minimum probably in December or January. The following statement gives the mean and extreme temperatures of the air over the sea area from which the wind blows during five months from December to May, and at Madras.

		Madras.	*Bay of Bengal.*
December	Max.	84°	79°
	Mean	75·5°	77°
	Min.	70°	75°
February	Max.	87°	80°
	Mean	77°	78°
	Min.	68°	76°
March	Max.	89°	82°
	Mean.	80°	80°
	Min.	72°	78°
April	Max.	93°	83°
	Mean.	84°	81°
	Min.	77°	79°
May	Max.	98°	84°
	Mean	87°	82°
	Min.	81°	80°

These data show clearly that in December the air coming from the sea moves during some hours of the day over a surface considerably warmer than itself and during the night over a surface considerably cooler than itself. Hence during the day ascensional movement and replacement of the lower slow moving layers of air by cooler air from more rapidly moving higher layers are active, while during probably the whole of the night, and possibly part of the day as well, these actions are altogether absent. In March the temperature of the air over the

and is about as much in excess (7° F) of the temperature of the air over the sea during the day as it is in defect (6° F.) during the night and the mean temperature of the air over land and sea are practically the same. Convective action and ascensional movement of the air while moving over the land is therefore more vigorous during this month than in December or January. Table VII shows that the ratios of the greatest and least movements to the mean in March are 1·8 and 0·4, while in December they are 1·7 and 0·5. In March the greatest variations from the mean are —4·1 and + 5·3 miles per hour; in December they are —3·6 and + 5·1 miles per hour. In April the convective action is still more vigorous and extends over a greater part of the 24 hours than in the preceding months. The ratios of the extreme to the mean are 1·7 and 0·4, and the variations of the extreme from the mean —5·2 and + 5·8 miles per hour. It must be remembered that the minimum temperature of the air over the land is during this month still less than the minimum of the air over the sea. On the contrary in May the minimum over the land is higher than the minimum over the sea and hence it is probable that convective action is active more or less throughout nearly the whole of the 24 hours of the day. (If it were *equally* active or inactive throughout the 24 hours, there would of course be no diurnal periodic variation, as in the open sea). This alone makes the air movement more vigorous, but the daily periodic variations will not be so great. We must also remember that the mean air movement at a given height above the ground is necessarily greater in April than in March, and in May than in April, on account of the increasing extent and intensity of the hot area in the interior (referred to in § 15) to which the air movement at this season is directed. The ratios of the extremes to the mean in May are 0·7 and 1·3; the variations of the extremes from the mean are 2·8 and 3·4 miles per hour.

Another factor which tends to produce large diurnal variations in these months is the effect of the land and sea breeze system. From the middle of October to the middle or end of April the sea breeze is in the same direction as and tends to increase the air movement during the day, while during the night the land wind is in the opposite direction and opposes it.

From June to September the direction of the wind is southwesterly. During this period the air is moving over a surface which increases in temperature from west to east. Hence, as in May, convective action is probably active during the greater part of the 24 hours of the day. The effect of the land and sea breeze system is briefly this; the land breeze aids the prevailing wind during the night and the sea-breeze opposes it during the day. Hence large diurnal variations are not to be expected.

These considerations appear to be sufficient to account for the different character of the diurnal variations of the air movement observed at different times of the year. They also show the close relation that exists between the diurnal variations of temperature and air movement. This is applied in § 43 to make an estimate of the magnitude of the land and sea breeze system at different hours of the day.

Vertical temperature distribution.

23. The following statement shows the mean differences between the minimum temperature of the air (4 feet

above ground level) and the grass minimum for each month.

Month ...	January.	February.	March.	April.	May.	June.	July.	August.	September.	October	November.	December.
Difference ...	4·4°	4·7°	3·5°	2·5°	1·9°	1·7°	1·9°	1·9°	2·1°	2·4°	2·8°	3·4°

These indicate the greater stability during some period in the night of the lower layers of air in November to April than in May to September. Unfortunately data are not available to enable us to estimate the differences between the maximum temperature of the ground and the maximum temperature of the air for each month. In the absence of data concerning the maximum temperature of surface of ground the following statement is given showing the difference between the sun maximum and the maximum temperature of the air—

Month ...	January.	February.	March.	April.	May.	June.	July.	August	September.	October.	November.	December.
Difference ...	53·8°	53·1°	51·3°	48·8°	45·2°	42·2°	43·1°	46·3°	48·1°	50·1°	53·4°	52·2°

If the differences between the maximum temperature of the ground and the maximum temperature of the air are of the same character as tho differences shown here, they indicate a greater instability of the lower layers of air during some period in the day in November to April than in May to September. These conclusions based on the two statements given above rest on the further assumption that the phases of the temperatures whose differences have been evaluated are the same. On this matter there is no evidence, and hence no great reliance must be placed on the conclusions deduced from them. They point rather to the need for additional observational data and the insufficiency of those available at present.

Maxima and minima.

24. The following statement gives the approximate times of maxima and minima of the air movement during the day in different months and for the whole year—

Month.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
Maximum.	2-30 P.M.	3 P.M.	3 P.M.	2-30 P.M.	2-30 P.M.	11 A.M.	11 A.M.	11 A.M.	10-30 A.M.	2-30 P.M.	2 P.M.	2 P.M.	2 P.M.
Minimum.	6·0 A.M.	5-30 A.M.	4-30 A.M.	4-30 A.M.	4-30 A.M.	5 A.M.	5 A.M.	5-30 A.M.	5-30 A.M.	5-30 A.M.	5-30 A.M.	5-30 A.M.	5-30 A.M.

The most noteworthy feature in the above is the time of maximum during the southwest monsoon period, *i.e.*, 11 A.M. The diagrams in Plate V and VI show that this coincides with the instant when the wind is most westerly in direction and is

just before the wind undergoes a large and rapid change in direction. This rapid change in direction and magnitude will be shown later to be due to the interference of the land and sea breeze, and the incidence of the maximum at such an early hour is to be ascribed to the same disturbing cause.

Direction considered.

25. In the foregoing paragraphs the attempt has been made to account for the observed air movement by tracing the relations between its amount and variations, and the various conditions (temperature and pressure distributions) which accompany these. In order to obtain other quantitative relations it is necessary to take into consideration the direction of the movement—a factor which for convenience in a preliminary examination was purposely ignored in the above discussion.

Wind roses.

26. The following statement shows the percentage number of calm hours and of miles of wind from different directions in each month of the year.

TABLE VIII.

The percentage number of calm hours and of miles of wind from different directions in different months—

Direction.	January.	February.	March.	April.	May.	June.	July.	August	September.	October.	November.	December.
N. ...	5	4	...	...	1	...	...	...	...	6	15	19
N.N.E. ...	21	7	...	...	2	...	...		...	7	37	34
N.E. ...	33	10	1	1	...	...	...	1	1	6	28	17
E.N.E. ...	20	18	4	3	2	1	2	1	2	8	7	7
E. ...	2	18	9	3	1	1	2	2	3	7	2	2
E.S.E. ...	5	13	17	8	5	3	2	3	5	5	1	1
S.E. ...	3	15	35	39	17	7	5	7	8	8	2	...
S.S.E. ...	1	9	22	31	30	12	10	9	8	6	1	...
S. ...	1	2	6	10	19	10	9	19	8	4	1	...
S.S.W. ...	...	2	4	5	9	5	6	11	10	5	...	...
S.W. ...	...	1	1	2	5	11	15	22	19	4	1	...
W.S.W. ...	...	...	...	1	4	25	29	25	15	4	...	...
W. ...	...	...	...	...	3	17	20	16	14	4	...	...
W.N.W. ...	...	...	...	...	2	7	8	8	9	5	1	...
N.W. ...	...	...	...	...	2	2	3	3	4	7	4	2
N.N.W. ...	...	...	...	...	2	2	2	2	1	13	12	7
Calm ...	2·9	4·7	3·0	3·4	2·0	3·0	1·5	1·8	3·0	6·2	2·4	2·6

The data for January, February, May, July, October and November are shown in the form of wind roses in Plate III.

This table shows that in December 81 per cent. of the movement recorded comes from directions between north and northeast approximately. In April 80 per cent.

of the movement is between southeast and south, and in January 74 per cent. between north-northeast and east-northeast. In February when the mean air movement is a minimum, the directions of the air movement are distributed between north and south-southeast with a moderate concentration in the easterly direction. In October when the movement is at an absolute minimum for the whole year, winds are almost uniformly distributed in all directions. In June and July there are maxima in the distribution in the directions south-southeast and west with a minimum at south-southwest. It will be shown later that these peculiarities are due to :—

(1) an increase in the velocity at sunrise and a strengthening of the land wind in the morning hours after sunrise.

(2) the setting in of the sea breeze in the early afternoon hours.

Southerly and westerly components.

27. We shall now proceed to deal with the data taking into account the direction as well as the magnitude of the movements.

For this purpose, each recorded velocity was resolved into its southerly and westerly components. These components were entered on separate sheets under the appropriate hours, each sheet being sufficient to take the hourly components for all hours of the day, for all days of a month. The means of these values were now deduced, and from these means the data contained in Tables IX and XIII were obtained, which give the mean hourly components, southerly and westerly, for each hour of the mean day of each month. From these we can find the resultant velocity at any hour or the mean resultant for any month by simply combining in the usual way the two components. These will show how the wind varies in magnitude and direction

(1) from month to month.

(2) from hour to hour during the mean day in each month.

Mean monthly velocities

28. We shall now consider these annual and diurnal variations of the movement in direction as well as magnitude and their relations to other data defining the meteorological conditions. The mean southerly and westerly components and their resultants, the mean hourly velocity for each month, are given in the following table for convenience.

Month.	January.	February.	March	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
South component	−3·33	0·15	2·95	6·13	7·25	4·35	3·35	3·27	2·55	−0·68	−5·32	−6·14	1·32
West component	−4·65	−3·77	−3·93	−3·95	−1·64	2·98	4·20	2·92	2·44	−0·33	−1·94	−2·85	−0·73
Resultant ...	5·74	3·75	3·60	7·29	7·47	5·30	5·42	4·38	3·54	0·78	5·66	6·77	1·52

The directions of these resultants are given to the nearest degree in the following table.

Month.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Direction of resultant	N 51° E	S 87° E	S 45° E	S 33° E	S 13° E	S 42° W	S 50° W	S 42° W	S 41° W	[illegible]	[illegible]	[illegible]

These velocities are plotted in Fig. 2, Plate I.

It will be seen that the resultant air movement is from directions—

(1) between north and east during the transition and cold weather periods.

(2) between east and south during the hot weather period and

(3) between south and west during the southwest monsoon period.

Relations to pressure distribution.

29. *January.* The mean velocity is 5·24 miles per hour and its direction is N 51° E. The mean pressure distribution is shown in Plate 24 of the Climatological Atlas of India. From this we deduce that the mean gradient is ·00292 inch per 15 nautical miles, and the angle made by the resultant wind direction with the normal to the isobars, the direction of the gradient, is about 39°. During this month the northeast monsoon is established over the Peninsula and the adjoining seas. The mean temperature is very uniform but it slowly increases from north to south.

February. The mean velocity is 5·78 miles per hour and its direction is S 87° E or very nearly easterly. During this month the pressure distribution is more uniform over the land area than in January, considerable changes having taken place owing to increase in temperature in the interior of the Peninsula. The interior is hotter on the average than the coast, and the daily range is much greater inland. The hottest area gradually moves northwards to the Ceded Districts and Deccan, the mean temperature here being 2° to 5° higher than on the Madras coast and the maximum temperature from 5° to 9° higher. Hence the wind direction is more easterly than in January, when there is no high temperature area and consequent tendency to produce a low pressure region to the northwestward of Madras. It should be noticed that over the sea area very little change in pressure distribution has occurred since the preceding month.

March. The mean velocity is 5·6 miles per hour and its direction is S 45° E. The angle made by mean wind direction with the direction of the gradient is 30°. Over that part of the Bay to the east of the Madras coast pressure is high and apparently uniform; over the Peninsula it very gradually falls in directions away from this area. The hottest area is in the same position as in February but has extended, and the differences in the mean temperatures of this area and the Madras coast are now 5° to 7° and in the maximum temperatures as much as 10°. Hence the tendency to establish a low pressure area here, and indraught from surrounding seas, is much stronger than in February, and that such a low pressure area is actually formed here during the day is shown in Plate 13 of the Climatological Atlas. With these conditions southeasterly winds set in on the Madras coast.

April. The mean velocity is 7·29 miles per hour and its direction is S. 33° E. The mean gradient is ·00384 inch per 15 nautical miles, and the angle between the mean wind direction and gradient is 17°. The mean velocity is thus more southerly and greater than in March. A considerable change has taken place in the pressure distribution, pressure being now permanently lower throughout the day in the interior of the Peninsula than at the coast. The low pressure area has now extended in a northerly and easterly direction from the Ceded Districts into northern India while over the Bay pressure is high in the south and east. In the afternoon hours gradients become much steeper; see Plate 14 of the Climatological Atlas. The area of lower pressure is also the area of highest mean and maximum temperatures.

May. The mean velocity is 7·47 miles per hour and its direction is S. 13° E. The mean gradient appears to be about ·00492 inch per 15 nautical miles. The direction has become still more southerly since April with the change that has taken place in the pressure distribution. In this distribution the isobars over the land area run almost parallel to the west coast and turn rather suddenly eastwards when they enter the Bay. This distribution tends to establish westerly and northwesterly winds over the greater part of the Peninsula. The hottest area which affects the air movement on the Madras coast now includes the eastern half of the Ceded Districts, the Deccan and Circars, and pressure is lower here than in the south and west of the Peninsula. Gradients are much steeper than in April.

June. The mean velocity is 5·9 miles per hour and its direction S. 42° W. The mean gradient is ·00495 inch per 15 nautical miles, and the angle between the mean wind direction and the gradient is about 12°. This is the first month of the southwest monsoon season which lasts till the second week of October over the south of the Peninsula. The air movement is no longer solely determined by actions due to temperature conditions in the province, though it is modified by these to a slight extent during this season.

Temperature is higher over the eastern half of the Peninsula than over the western half where the more general and abundant monsoon rainfall has effected a great reduction since the previous month; it is highest in the region round Nellore.

July. The mean velocity is 5·5 miles per hour and its direction is S. 50° W. *i. e.*, slightly more westerly than in June. The mean gradient at Madras is ·00528 inch per 15 nautical miles, and the angle between the mean wind direction and the gradient is 17°. The velocity is thus not quite so high as in June and is slightly more westerly. Both of these changes appear to be due to changes that have taken place in the temperature distribution over the province. The hottest area now overlies the Madras coast districts extending from Masulipatam to Tuticorin but does not include the Circars and Deccan, where rainfall has produced a considerable reduction in temperature; very little rain is received on the Madras coast. Thus the hottest area is on the whole further south than in June and *relatively* there is more ascensional movement at Madras. The southerly component will in consequence not be so strong. The temperature differences between the Madras and Malabar coasts are nearly but not

quite as great as in June; the action of these on the air movement will therefore be almost unchanged.

August. The mean velocity is 4·4 miles per hour and its direction is S. 42° W. The mean gradient is ·00474 inch per 15 nautical miles and the angle is about 7°. The most important change in temperature since July is the fall on the Madras coast and the establishment of a more uniform distribution over the south of the Presidency. The temperature differences between the east and west coasts are less, and hence they will have less effect in absolute amount on the air movement than in July and August. The highest temperatures are experienced at Trichinopoly, Madura and Nellore. During this month and the next, rainfall becomes gradually heavier in the eastern and lighter in the western divisions of the Presidency.

September. The mean velocity is 3·5 miles per hour and its direction is S. 44° W. The mean gradient is about ·00288 inch per 15 nautical miles and the angle about 10°.

In this month temperature becomes still more uniform over the south of the Peninsula, but the eastern half is still hotter than the western half; the differences are about 5° F. in the mean temperatures, and not more than 10° F. in maximum temperatures.

October. The mean velocity is 0·78 mile per hour and its direction is N. 29. E. This movement forms part of a cyclonic circulation round the depression which forms over the south or southwest of the Bay in this month (see Plate 33 of the Climatological Atlas). In this month, as we have already remarked, there are generally two totally dissimilar periods characterised by widely different meteorological conditions and air movements from opposite quarters. The change from the one to the other takes place more or less abruptly during the second week of the month on the average. Hence the method hitherto employed, of taking means of the air movements for the whole month is very unsuitable. The resultant movement is very small and any error becomes correspondingly important and the relations of the movement to the pressure distribution become difficult or impossible to determino.

November. The velocity is 5·7 miles per hour and the direction is N. 20° E. The mean gradient is ·00294 inch per 15 nautical miles, and the angle between the mean wind direction and the gradient is about 37°. Temperature is now very uniform and increases slowly from north to south; its effect on the movement must be small.

December. The velocity is 6·8 miles per hour and its direction is N. 25° E. The mean gradient at Madras is ·00370 inch per 15 nautical miles and the angle is about 40°. Temperature increases slightly more rapidly from north to south than in November, but the maximum temperatures are very uniform throughout the Peninsula. The chief differences are in the minimum temperatures which are much lower in the interior than at the coast and increase rather rapidly from north to south.

The accuracy of the results.

30. It has not been possible to determine the relation between the mean velocity of the wind and mean pressure gradient at Madras for all months of the year. Those that have been evaluated are

given below—the gradients are given in inches of mercury per 15 nautical miles in all cases.

Month.	November.	December.	January.	April.	June.	July.	August.	September.
Gradient ...	·00291	·00370	·00292	·00384	·00495	·00528	·00474	·00288
Velocity ...	5·7	6·8	5·2	7·3	5·9	5·5	4·4	3·5
Angle ...	37°	40°	39°	17°	12°	17°	7°	10°

The most uncertain elements in these data are the values of the angles, which are difficult to determine with any confidence. Such as they are, they indicate that the wind makes a greater angle with the direction of the gradient when the air movement is from the sea than when it is from the land.

The effects of friction, etc.

31. Assume that the motion of the air is horizontal and let F denote the acceleration along the gradient due to the pressure distribution.

θ the angle *between the gradient and the direction in which the air is moving.*

v the velocity of the air.

κv the acceleration due to the forces opposing the motion of the air, *e.g.*, friction, etc.

Resolving along the tangent and normal to the air path, we get

$$v\frac{dv}{ds} = F \operatorname{Cos}\theta - \kappa v \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (A)$$

$$\frac{v^2}{\rho} = F \operatorname{Sin}\theta - 2\,\omega\, v \operatorname{Sin}\lambda \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (B)$$

where ρ is the radius of curvature of the air path, λ the latitude and ω the angular velocity of rotation of the earth (in space).

It is usual to put the left hand members of (A) and (B) zero and if we do this, the relations reduce to—

$$F \operatorname{Cos}\theta = \kappa_1 v \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (1)$$

$$\text{F} \operatorname{Sin}\theta = 2\,\omega\, v \operatorname{Sin}\lambda \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (2)$$

$$\text{hence} \quad \kappa = \frac{2\,\omega \operatorname{Sin}\lambda}{\tan\theta} \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (3)$$

By means of (3) the values of κ have been determined from the data given in the preceding table. They are contained in the following statement :—

Month	November.	December.	January.	April.	June.	July.	August.	September.
Friction constant . . .	·000011	·000039	·000041	·000108	·000155	·000103	·000263	·000187

In this method it is necessary to know the angle θ with accuracy. Any uncertainty in the value of the angle, especially when the angle is small as in June to September, is of serious importance.

The value of the friction constant k can also be deduced from relation (1) by the help of the data given in section 30. In this case the value of θ, unless it becomes large, is of subordinate importance. The results obtained by this method are contained in the following statement:—

Month.	November.	December.	January.	April.	June.	July.	August.	September.
Friction constant . . .	·000096	·000097	·000099	·000117	·000151	·000213	·000243	·000155

These results appear to show that the value of the friction constant depends on the season, and with it on the direction of the prevailing wind. While this may be to some extent the case, it does not appear sufficient to account for the enormous differences shown in the above tables; the large differences in the values deduced by the two methods for the months November to January are also unaccounted for. These discrepancies are due principally to the assumption by which we derived equations (1) and (2) *i.e.*, to assuming that the accelerations, $v\dfrac{dv}{ds}$ and $\dfrac{v^2}{\rho}$, are zero in (A) and (B). The following considerations indicate that $v\dfrac{dv}{ds}$ in equation (A) is negative during November—January and positive during the south-west monsoon period. It is also highly probable that the velocity v is under-estimated (see section 8).

The effects of friction.

32. When a mass of air moving over the surface of the sea passes to the land, the forces opposing its motion become suddenly greater and its velocity will in consequence begin to diminish. It will continue to diminish and change in direction until it has adapted its movement to the changed conditions. If such a diminution in the velocity of the layers near the surface occurs, it is evident that the stream lines at higher levels cannot be horizontal, over and near the coast; the air from the ocean will be forced to ascend to a higher level on reaching the land. If the air be saturated with water vapour, rainfall will be heavier near the coast than further inland when the stream lines have become horizontal again and the ascending movement due to this cause has ceased. Now this is the case over the south of the Presidency during the months October to December; the rainfall is greater on the coast than inland. See Plates 111, 112 and 113 of the Climatological Atlas of India. Further the diurnal variation in the strength of the wind is very small over the ocean, while over the land it is great. We might therefore expect this forced upward movement to be greater during the night than during the day. The records of the hourly rainfall at Madras show that in October the rainfall during the night hours (6 P.M. to 6 A.M.) is 45 per cent. greater than during the day hours (6 A.M. to 6 P.M.), 15 per cent. greater in November, and 3 per cent. greater in December (when the rainfall is much smaller than in the other two months).

These interesting results give some support to the inferences stated above*. During November, December and January then, there appears to be sufficient reason from these considerations to take $v\frac{dv}{ds}$ negative in (A). Conversely during the south-west monsoon period it is positive. Direct observations bearing on this question are available (see section 8), but not in a form suitable for our purpose at present and their consideration and discussion must be deferred to a future occasion. It is not possible at present to evaluate $v\frac{dv}{ds}$, nor to correct v and find the true value of κ: when these are effected it is easy to see that they will tend to make the values of κ more concordant. Other considerations, which cannot be given here indicate that the value probably lies between ·00004 and ·00007.

Limits of application.

33. In section 31 it has been assumed that the movement of the air is horizontal. This assumption is not correct, for the important vertical movements (one has been mentioned in the preceding section) are ignored. The data used in (A) or (1) have been deduced from the mean air movement and mean pressure distribution. Now the mean air movement represents the resultant of movements which differ widely in strength and direction; similar remarks hold for the mean pressure distribution. By taking the mean of such movements and the average of such pressure distributions we obtain a set of data which may not correspond to any actual or possible simultaneous conditions. Such data *may* therefore be very misleading when we try to give them a dynamical interpretation on the simple but imperfect theory stated above.

In the foregoing discussion, some of the more important relations between the mean air movement and the pressure and temperature distributions have been pointed out and analysed. In the following sections the diurnal variations of the velocity are considered.

Tables and formulæ.

34. The mean southerly components for each hour of the day, and their variations from the mean for the whole day, for each month and the year are given in Table IX. Table XIII gives similarly the westerly components and their variations. The data in these two tables are derived in the manner already explained in section 27. Tables X and XI contain the constants of the periodic formulæ which represent the variations in the southerly components and Table XII contains the values of the variations calculated from the formulæ.

* It is well to remember that there are other causes acting and tending to produce effects similar to these.

Table IX—Mean hourly southerly components of the wind.

Hour.	January. Mean.	January. Difference.	February. Mean.	February. Difference.	March. Mean.	March. Difference.	April. Mean.	April. Difference.	May. Mean.	May. Difference.	June. Mean.	June. Difference.	July. Mean.	July. Difference.	August. Mean.	August. Difference.	September. Mean.	September. Difference.	October. Mean.	October. Difference.	November. Mean.	November. Difference.	December. Mean.	December. Difference.	Year. Mean.	Year. Difference.
Midnight	−1·11	1·11	0·10	−0·08	2·06	−1·31	3·33	−0·20	7·02	0·01	3·51	1·14	5·10	1·53	3·26	2·11	1·16	1·62	−0·15	0·31	−3·31	1·84	−3·73	0·33	0·21	0·29
1	−1·82	1·03	0·06	−0·11	1·33	−3·11	2·80	−1·91	6·77	−0·31	3·18	0·81	6·31	1·35	3·01	0·75	6·10	1·30	−0·13	0·03	−3·11	2·11	−3·92	6·33	1·30	0·33
2	−1·86	1·36	0·03	−0·18	1·61	−1·33	2·59	−3·63	6·83	−0·63	4·28	0·11	1·17	0·91	4·43	1·81	8·10	1·57	−0·09	0·03	−3·05	2·32	−3·17	0·77	1·88	0·31
3	−1·37	1·30	0·10	−0·14	1·33	−3·38	2·71	−3·10	6·10	−1·10	4·21	−0·15	2·24	0·13	6·14	0·37	3·80	1·30	−0·10	0·38	−3·80	2·08	−3·14	2·25	1·30	0·92
4	−1·71	1·50	−0·01	−0·10	1·63	−1·17	1·33	−3·81	3·81	−1·43	3·65	−0·56	3·33	−0·01	3·81	0·87	3·30	0·11	−0·08	0·80	−0·17	2·13	−3·18	2·50	1·20	0·06
5	−1·33	1·37	0·03	−0·13	1·61	−0·36	0·50	−2·05	3·43	−1·25	3·33	−0·81	3·00	−0·32	3·30	0·16	0·07	0·10	−0·05	0·73	−3·13	3·13	−3·10	0·31	1·73	−0·13
6	−1·80	1·48	0·09	−0·10	1·53	−0·67	3·12	−1·03	3·95	−1·35	3·86	−0·70	2·56	−0·60	2·18	−0·53	1·39	0·18	0·07	0·23	−3·27	1·83	−3·11	1·76	1·17	−0·39
7	−1·11	1·34	0·10	−0·17	1·03	−1·43	5·01	−0·41	7·41	0·13	3·91	−0·61	3·33	−0·16	3·34	0·07	3·31	0·79	0·16	0·72	−0·11	1·11	−1·10	1·75	1·23	0·53
8	−3·44	0·69	0·19	0·11	1·59	0·84	7·33	1·65	6·31	−0·37	3·07	−1·09	0·77	−0·77	3·13	−0·12	7·18	−1·80	−0·03	0·63	−3·30	0·11	−6·09	0·08	1·31	[illegible]
9	−6·47	−1·16	0·57	0·16	3·11	1·26	8·01	6·11	3·73	−1·30	3·61	−3·03	1·63	−1·33	1·78	−1·93	1·31	−1·05	−0·35	0·15	−2·12	−1·97	−7·30	−1·71	0·91	−0·91
10	−4·18	−1·31	0·23	0·69	6·11	2·13	8·37	6·14	8·61	−1·17	1·88	−3·11	0·73	−3·73	0·37	−2·70	0·58	−1·97	−1·15	−0·18	−3·30	−1·53	−9·07	−0·78	0·11	−1·61
11	−2·06	−1·31	0·23	0·70	6·35	2·43	8·31	7·82	3·93	−1·13	1·86	−3·10	0·83	−3·11	0·13	−3·16	0·10	−0·65	−1·43	−0·73	−3·06	−2·31	−7·39	−3·18	0·23	−1·15
Noon	−4·38	−1·03	0·73	0·71	6·33	2·03	8·49	3·17	7·80	−2·10	2·06	−2·70	0·33	−3·30	0·11	−3·13	−0·13	−1·01	−1·38	−1·11	−1·15	−1·83	−9·52	−3·11	0·78	−1·13
13	−6·37	−1·44	0·71	0·30	6·03	2·69	0·84	3·71	8·03	0·63	2·35	−2·05	0·73	−1·43	0·78	−2·31	0·50	−2·03	−1·77	−1·09	−4·30	−0·18	−9·79	−3·73	0·18	−2·00
14	−6·62	−1·42	0·22	0·29	7·73	2·36	8·07	3·52	9·03	1·73	3·11	−3·63	−1·83	−1·77	1·06	−1·88	0·83	−1·79	−1·38	−1·18	−1·63	−2·11	−9·71	−3·75	0·76	−2·10
15	−5·37	−2·13	0·18	0·10	6·71	1·73	4·16	3·31	0·39	1·01	0·63	0·31	3·66	−0·61	2·39	−2·79	1·71	−0·83	−1·70	−0·77	−2·18	−2·11	−9·15	−7·31	1·73	−0·71
16	−3·31	−1·48	0·03	−0·13	6·18	2·31	8·46	1·73	4·15	2·77	3·43	1·61	0·16	0·85	3·30	0·03	2·68	−4·48	−1·66	−0·44	−2·77	−2·11	−9·90	−2·11	1·38	0·91
17	−1·83	−1·20	−0·21	−0·61	5·18	1·30	3·71	1·01	8·73	1·13	1·10	1·70	0·35	1·37	3·31	0·31	2·80	0·83	−1·16	−0·37	−2·10	−1·08	−7·31	−1·11	1·73	1·31
18	−3·71	−0·16	−0·13	−0·83	1·95	0·08	0·40	0·13	4·11	0·73	0·86	1·83	5·83	1·73	3·91	0·33	2·67	−1·1	−0·71	−1·11	−2·11	−4·93	−6·8	0·04	1·77	2·33
19	−3·83	0·06	−0·36	−0·31	3·23	−0·18	3·70	−0·33	4·38	0·00	6·93	1·63	5·85	0·11	1·69	0·81	2·91	0·39	−0·77	−0·73	−1·77	1·33	−3·31	0·13	1·79	2·47
20	−3·16	0·33	−0·17	−0·33	3·13	−0·23	3·33	−2·33	8·10	0·86	6·50	2·19	5·71	1·33	6·41	1·31	3·73	2·31	−0·57	0·11	−1·12	0·85	−3·71	0·90	1·96	0·40
21	−2·33	1·35	−0·13	−0·81	3·63	−0·1	3·11	−0·08	8·19	0·93	0·33	1·61	5·81	2·03	6·01	1·69	3·16	0·13	−2·43	0·93	−1·13	1·09	−1·85	1·18	2·06	2·71
22	−3·36	0·81	−0·13	−0·91	3·78	−2·18	2·33	−1·18	8·06	0·70	4·31	2·15	5·51	3·01	3·10	1·23	3·33	1·63	−0·00	0·60	−3·73	1·48	−1·31	1·61	2·11	0·78
23	−2·33	1·20	0·09	−0·87	2·33	−1·57	6·18	−1·50	7·62	0·31	6·13	2·77	5·81	1·73	3·40	2·13	3·53	1·33	−0·19	0·18	−3·73	1·71	−6·18	1·31	2·19	0·77
Mean	−2·33	—	0·13	−0·09	3·97	—	5·13	—	7·35	.	4·35	—	3·35	—	3·77	—	0·35	—	−2·21	—	−3·21	—	−4·10	—	1·81	—

TABLE X.—*Constants of the periodical formula (I) for the diurnal variation of the southerly component of the wind at Madras computed from Table IX.*

Month.	p_1.	q_1.	p_2.	q_2.	p_3.	q_3.	p_4.	q_4.
January	1·537	0·900	−0·246	−0·028	−0·225	−0·213	0·251	0·224
February	−0·367	0·184	0·326	−0·040	−0·041	−0·008	−0·037	−0·022
March	−2·468	−0·982	0·589	−0·068	0·261	0·096	−0·338	−0·085
April	−3·126	−1·400	0·675	−0·338	0·451	−0·055	−0·294	0·159
May	−0·130	−1·458	−0·116	0·273	0·378	−0·557	−0·091	0·380
June	1·692	−1·499	−0·738	0·005	0·454	−0·248	−0·060	0·082
July	2·070	−1·134	−0·802	−0·190	0·435	−0·006	−0·088	0·103
August	2·097	−0·375	−0·489	−0·028	0·551	−0·166	−0·060	0·115
September	1·741	0·148	−0·435	0·195	0·442	−0·014	−0·025	0·149
October	0·715	0·510	−0·267	−0·210	0·134	−0·020	0·002	0·063
November	2·527	1·041	−0·630	−0·202	−0·076	−0·047	0·263	0·097
December	3·134	1·360	−0·922	−0·124	−0·157	−0·125	0·363	0·179
YEAR	0·784	−0·226	−0·256	−0·061	0·215	−0·115	−0·007	0·120

TABLE XI.—*Constants of the formula (II) computed from Table X.*

Month.	U_1.	u_1.	U_2.	u_2.	U_3.	u_3.	U_4.	u_4.
		° ′		° ′		° ′		° ′
January	1·781	59 39	0·248	263 31	0·310	226 34	0·344	49 22
February	0·411	296 38	0·328	97 0	0·042	258 58	0·043	239 16
March	2·675	248 28	0·593	96 35	0·278	69 48	0·348	255 53
April	3·425	245 52	0·755	116 36	0·454	96 57	0·334	298 24
May	1·462	185 6	0·297	336 59	0·673	145 50	0·382	346 32
June	2·260	131 32	0·738	270 24	0·517	118 39	0·102	323 48
July	2·360	118 43	0·824	256 40	0·436	90 47	0·135	319 29
August	2·130	100 8	0·450	266 43	0·575	106 46	0·130	332 27
September	1·747	85 8	0·477	294 9	0·442	91 49	0·151	350 29
October	0·878	54 30	0·340	231 40	0·135	98 29	0·063	0 11
November	2·733	67 37	0·662	252 13	0·089	238 16	0·280	69 45
December	3·416	66 33	0·930	262 20	0·201	231 28	0·405	63 45
YEAR	0·516	106 5	0·263	256 36	0·244	118 8	0·120	359 39

TABLE XII.—*Showing values computed from formulæ giving diurnal variation of southerly components (Table XI.)*

Hour.		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
Midnight	...	1·32	−0·12	−1·97	−2·29	0·04	1·31	1·62	2·10	1·72	0·57	2·06	2·42	0·73
1	...	1·51	−0·12	−2·16	−2·71	−0·31	0·79	1·26	1·53	1·87	0·51	2·18	2·65	0·81
2	...	1·48	−0·10	−2·20	−3·13	−0·86	0·20	0·76	1·32	1·66	0·53	2·12	2·66	0·47
3	...	1·44	−0·11	−2·30	−3·61	−1·42	−0·30	0·25	0·74	1·24	0·51	2·09	2·71	0·11
4	...	1·55	−0·14	−2·46	−3·84	−1·69	−0·51	−0·19	0·32	0·83	0·57	2·18	2·93	−0·01
5	...	1·72	−0·19	−2·48	−3·48	−1·43	−0·62	−0·30	0·19	0·62	0·68	2·25	3·09	0·00
6	...	1·62	−0·18	−2·01	−2·32	−0·86	−0·57	−0·43	0·23	0·61	0·80	1·97	2·76	0·11
7	...	1·01	−0·05	−0·80	−0·60	−0·47	−0·70	−0·49	0·12	0·41	0·81	1·19	1·63	0·16
8	...	−0·02	0·17	0·51	1·04	−0·63	−1·23	−0·85	−0·43	−0·11	0·58	0·10	−0·01	−0·10
9	...	−0·99	0·44	1·72	2·13	−1·35	−2·03	−1·68	−1·38	−1·02	0·15	−1·19	−1·70	−0·57
10	...	−1·52	0·64	2·35	2·60	−1·74	−2·88	−2·64	−2·46	−1·95	−0·38	−2·07	−2·56	−1·09
11	...	−1·50	0·72	2·47	2·77	−1·51	−3·25	−3·33	−3·18	−2·58	−0·85	−2·55	−3·35	−1·34
Noon	...	−1·30	0·70	2·47	3·07	−0·46	−2·91	−3·40	−3·21	−2·64	−1·11	−2·82	−3·51	−1·35
13	...	−1·31	0·56	2·64	3·51	0·45	−1·99	−2·76	−2·37	−2·19	−1·19	−3·06	−3·63	−0·93
14	...	−1·66	0·36	2·65	3·77	1·91	−0·72	−1·61	−1·60	−1·45	−1·12	−3·22	−3·36	−0·53
15	...	−2·02	0·11	2·84	3·51	2·14	0·42	−0·45	−0·63	−0·80	−0·96	−3·09	−3·67	−0·31
16	...	−2·01	−0·18	2·24	2·60	1·71	1·13	0·59	−0·02	−0·29	−0·77	−2·32	−2·59	[illegible]
17	...	−1·41	−0·41	1·20	1·42	1·19	1·70	1·33	0·37	0·04	−0·52	−1·25	−1·55	0·13
18	...	−0·60	−0·36	0·15	0·38	0·92	1·93	1·85	0·63	0·23	−0·26	−0·21	−0·90	0·35
19	...	0·10	−0·55	−0·54	−0·21	0·95	[illegible]	2·15	0·90	0·39	−0·03	0·53	0·73	0·54
20	...	0·11	−0·43	−0·79	−0·56	0·99	2·15	2·29	1·23	0·33	0·16	0·93	1·09	0·51
21	...	0·53	0·28	−0·90	−0·87	[illegible]	2·15	2·21	1·56	0·66	0·27	1·03	1·11	[illegible]
22	...	0·66	−0·16	−1·17	−1·32	0·60	2·26	2·07	1·33	0·34	0·39	1·37	1·45	0·74
23	...	0·98	−0·12	−1·29	−1·53	0·31	1·78	1·87	2·10	1·36	0·49	1·75	1·94	0·79

TABLE XIII.—*Mean hourly westerly components of the wind.*

Hour.	January. Mean.	January. Diff.	February. Mean.	February. Diff.	March. Mean.	March. Diff.	April. Mean.	April. Diff.	May. Mean.	May. Diff.	June. Mean.	June. Diff.
Midnight	2·33	3·78	−2·80	1·77	−2·33	2·75	−2·27	3·58	−0·55	1·08	2·18	−0·87
1	−2·11	3·04	−2·75	0·02	−2·84	2·34	−1·74	2·31	−0·07	1·37	4·02	0·04
2	−1·98	2·07	−1·81	0·18	−1·53	2·45	−2·33	2·63	0·38	3·02	4·51	0·53
3	−1·83	2·13	−1·50	2·27	−1·37	2·91	−1·07	2·88	0·38	2·90	4·87	0·80
4	−2·75	2·32	−1·32	2·43	−1·41	2·87	−0·03	3·00	0·48	2·13	5·05	0·97
5	−1·00	2·30	−1·31	2·49	−1·22	2·76	−0·78	3·19	0·77	2·43	4·86	0·88
6	−1·64	2·45	−1·18	3·39	−1·34	2·74	−2·86	3·09	1·10	2·74	5·2	1·38
7	−1·03	3·41	−1·34	2·43	−1·42	2·56	−0·45	3·50	0·63	4·37	6·87	2·84
8	−3·50	1·49	−1·97	2·30	−0·99	2·92	0·98	4·51	4·58	6·03	9·32	5·14
9	−3·90	0·15	−3·50	2·07	−1·19	2·79	0·53	4·37	4·68	6·26	10·50	6·51
10	−5·20	−1·51	−3·80	−0·11	−2·83	1·10	−2·58	1·57	2·60	4·33	10·45	6·47
11	−6·71	−2·67	−5·50	−1·55	−5·78	−1·80	−6·01	−2·09	−0·80	0·78	9·24	5·80
Noon	−7·48	−5·40	−6·64	−3·87	−7·34	−5·58	−7·68	−3·73	−3·80	−2·34	7·34	3·25
13	−7·90	−5·81	−7·80	−6·05	−8·23	−4·30	−8·80	−4·83	−0·32	−4·47	−3·08	−3·10
14	−7·95	−3·90	−7·95	−4·19	−8·49	−4·31	−8·85	−4·91	−6·81	−5·17	3·07	−3·41
15	−7·65	−3·60	−7·33	−4·00	−8·59	−6·01	−8·94	−4·99	−7·13	−5·51	3·05	−3·93
16	−7·00	−2·09	−7·47	−3·72	−8·06	−4·03	−8·47	−4·52	−9·73	−5·08	−0·53	−4·52
17	−5·65	−1·60	−6·45	−2·68	−7·05	−3·07	−7·45	−3·50	−5·91	−4·27	−0·87	−4·83
18	−4·30	−0·25	−4·71	−0·93	−5·83	−3·10	−0·18	−0·19	−4·85	−3·33	−0·64	−4·62
19	−2·77	0·38	−4·03	−0·25	−4·76	−0·78	−5·33	−2·43	−4·21	−3·27	−0·39	−6·27
20	−3·41	0·84	−3·50	0·18	−4·37	−0·29	−4·80	−0·83	−3·39	−1·72	−0·25	−4·24
21	−5·13	6·92	−3·38	0·40	−5·93	0·05	−4·30	−0·25	−2·6	−2·04	0·33	−3·45
22	−3·83	1·02	−3·75	2·02	−3·39	0·30	−8·70	0·25	−2·05	−0·39	1·38	−3·00
23	−2·81	1·40	−3·47	1·30	−2·78	1·30	−2·33	0·82	−1·37	0·37	2·18	−2·73
Mean	−4·08	...	−5·77	...	−3·93	...	−3·92	...	−1·64	...	3·98	...

Hour.	July. Mean.	July. Diff.	August. Mean.	August. Diff.	September. Mean.	September. Diff.	October. Mean.	October. Diff.	November. Mean.	November. Diff.	December. Mean.	December. Diff.	Year. Mean.	Year. Diff.
Midnight	3·03	−2·37	2·07	−0·85	1·83	−1·21	−0·08	0·30	−1·38	0·59	−1·70	1·25	−0·28	0·67
1	3·34	−0·60	2·98	0·20	1·78	−0·69	0·17	0·35	−1·19	0·77	−1·69	1·39	0·10	0·91
2	4·22	0·02	5·18	0·19	2·32	−0·21	0·59	0·97	−1·07	0·87	−1·40	1·39	0·50	1·35
3	4·48	0·18	3·50	0·97	2·91	0·47	0·61	0·00	−1·06	0·88	−1·35	1·50	0·78	1·40
4	6·05	0·45	5·53	0·91	3·38	0·82	0·80	1·18	−0·90	1·04	−1·27	1·58	0·84	1·50
5	4·73	0·51	3·48	0·50	3·10	0·85	0·80	1·27	−0·77	1·33	−1·74	1·71	0·90	0·61
6	4·74	0·81	5·98	0·70	3·99	1·22	0·85	1·35	−0·81	1·43	−1·02	1·83	1·00	1·81
7	0·53	3·33	4·80	1·86	5·10	2·80	1·25	1·61	−0·38	1·58	−1·25	1·90	1·70	2·47
8	8·37	4·37	8·74	2·78	8·15	4·69	2·02	2·35	−0·81	1·05	−1·98	1·87	1·59	2·53
9	10·12	5·93	8·04	5·19	8·14	5·70	2·22	0·59	−0·81	1·05	2·97	−0·12	1·72	3·47
10	10·61	6·41	8·97	5·65	7·99	5·55	1·91	2·29	−1·38	0·40	−2·98	−1·15	1·82	3·57
11	10·21	5·93	7·97	3·05	7·28	4·84	0·64	1·32	−2·71	−0·77	−4·95	−1·80	0·20	1·05
Noon	8·89	4·65	6·99	3·77	5·63	2·10	−0·61	−0·05	−3·58	−2·64	−3·43	−2·60	−1·27	−0·12
13	7·13	2·05	4·93	2·01	3·66	1·22	−2	−1·71	−4·09	−2·35	−5·06	−2·79	−2·50	−2·75
14	4·31	0·87	3·69	−0·21	1·63	−0·76	−2·95	−2·57	−4·11	−2·17	−5·45	−2·60	−3·39	−2·64
15	3·97	−3·13	2·68	−2·36	−0·20	−2·64	−2·32	−2·93	−4·13	−2·19	−5·30	−3·65	−4·12	−3·87
16	0·38	−3·82	−0·01	−3·83	−1·35	−3·50	−3·25	−2·87	−3·68	−1·74	−4·58	−1·73	−4·29	−5·53
17	−0·45	−4·05	−3·48	−4·40	−1·94	−4·08	−2·54	−2·26	−4·80	−2·6	−3·40	−0·58	−3·61	−5·00
18	−0·71	−4·81	−1·87	−4·89	−2·67	−2·93	−1·92	−1·54	−2·37	−0·42	−2·72	0·13	−5·04	−2·30
19	−0·33	−4·58	−1·32	−4·21	−2·20	−2·64	−1·54	−1·19	−2·23	−0·39	−3·00	0·85	−2·64	−1·8
20	0·03	−4·12	−0·89	−3·81	−0·80	−3·38	−1·28	−0·90	−1·99	−0·05	−3·45	0·42	−0·29	−1·51
21	0·77	−2·42	0·05	−2·87	−0·44	−2·88	−0·04	−0·56	−1·84	0·10	−2·27	0·68	−1·78	−1·03
22	1·25	−2·76	0·74	−2·38	−0·18	−2·57	−0·00	−0·51	−2·77	0·17	−2·22	0·75	−1·56	−0·59
23	1·95	−2·16	2·65	−1·47	0·72	−1·72	−0·41	−0·03	−2·51	0·45	−1·93	1·90	−0·83	−0·08
Mean	4·20	...	2·98	...	2·44	...	−0·58	...	−1·94	...	−2·85	...	−0·75	...

TABLE XIV.—*Constants of the periodical formula (I) for the diurnal variation of the westerly component of the wind at Madras computed from Table XIII.*

Month.	p_1.	q_1.	p_2.	q_2.	p_3.	q_3.	p_4.	q_4.
January . . .	2·463	1·616	−0·965	−0·632	0·153	0·267	0·123	0·172
February . . .	2·196	2·210	−0·621	−0·939	0·058	0·289	0·042	0·091
March . . .	2·104	2·769	−0·610	−1·136	0·204	0·511	−0·175	0·072
April . . .	2·031	3·453	−0·780	−1·324	0·517	0·576	−0·311	0·163
May . . .	0·879	4·165	−0·707	−2·084	0·645	0·950	−0·415	−0·022
June . . .	−2·109	3·958	1·465	−1·264	−0·052	0·809	−0·237	0·013
July . . .	−2·743	3·575	1·844	−0·985	−0·323	0·570	−0·124	0·018
August . . .	−2·049	3·258	1·564	−0·917	−0·262	0·539	−0·135	−0·011
September . . .	−2·098	3·379	1·099	−1·201	−0·162	0·596	−0·161	−0·011
October . . .	0·261	2·010	0·112	−0·977	−0·065	0·515	−0·033	−0·109
November . . .	0·853	1·233	−0·484	−0·601	0·277	0·233	−0·017	0·031
December . . .	1·683	1·010	−0·798	−0·340	0·140	0·058	0·125	0·043
YEAR .	0·292	2·720	0·143	−1·034	0·100	0·484	−0·129	0·043

TABLE XV.—*Constants of the formula (II) computed from Table XIV.*

Month.	U_1.	u_1.	U_2.	u_2.	U_3.	u_3.	U_4.	u_4.
January . . .	2·946	56°44′	1·154	236°47′	0·176	60°23′	0·211	35°31′
February . . .	3·116	44°49′	1·121	213°32′	0·302	16°56′	0·099	25°1′
March . . .	3·477	37°14′	1·290	205°14′	0·610	25°50′	0·195	291°16′
April . . .	4·032	30°15′	1·537	210°30′	0·794	43°31′	0·442	291°35′
May . . .	4·257	11°55′	2·096	185°40′	1·149	34°13′	0·446	267°11′
June . . .	4·510	332°7′	1·937	130°44′	0·809	355°19′	0·237	275°8′
July . . .	4·467	322°7′	2·091	115°7′	0·655	330°28′	1·125	278°16′
August . . .	3·549	327°50′	1·905	119°7′	0·599	334°5′	0·135	255°20′
September . . .	3·978	328°10′	1·627	137°32′	0·618	344°45′	0·152	265°55′
October . . .	2·026	7°24′	0·984	173°28′	0·549	353°12′	0·114	196°51′
November . . .	1·517	35°36′	0·772	215°51′	0·312	41°37′	0·027	321°1′
December . . .	1·963	59°2′	0·857	246°55′	0·165	57°51′	0·132	71°1′
YEAR .	2·733	6°8′	1·045	172°8′	0·495	11°40′	0·133	255°20′

TABLE XVI.—*Shewing values computed from formulæ giving diurnal variation of westerly components (table XV).*

Hour.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
Midnight	1·77	1·70	1·61	1·40	0·88	—0·93	—1·35	—0·78	—1·32	0·28	0·59	1·15	0·40
1	2·04	2·04	2·22	2·26	1·60	—0·20	—0·51	—0·04	—0·58	0·61	0·77	1·29	0·97
2	2·08	2·24	2·62	2·88	2·08	0·75	0·11	0·48	0·03	0·90	0·88	1·33	1·36
3	2·05	2·24	2·67	3·00	2·15	0·92	0·32	0·63	0·20	1·08	0·94	1·41	1·49
4	2·22	2·33	2·52	2·78	1·94	0·74	0·28	0·50	0·54	1·04	1·01	1·58	1·46
5	2·48	2·45	2·44	2·79	2·05	0·98	0·37	0·46	0·79	1·16	1·20	1·80	1·56
6	2·61	2·51	2·66	3·29	2·99	1·48	1·01	0·93	1·52	1·33	1·46	1·84	1·97
7	2·32	2·54	3·04	4·11	4·56	3·04	2·34	2·05	2·83	1·72	1·67	1·54	2·64
8	1·44	2·09	3·08	4·43	5·93	4·91	4·13	3·49	4·37	2·26	1·63	0·83	3·24
9	0·11	1·22	2·38	3·56	5·98	6·11	5·72	5·01	5·56	2·59	1·18	—0·10	3·29
10	—1·39	—0·11	0·81	1·37	4·21	6·57	6·55	5·67	5·78	2·32	0·35	—1·06	2·58
11	—2·64	—1·54	—1·26	—1·40	1·11	5·47	6·21	5·25	4·93	1·37	—0·66	—1·90	1·23
Noon	—3·45	—2·86	—3·19	—3·78	—2·18	3·39	4·79	3·84	3·20	—0·12	—1·59	—2·51	—0·38
13	—3·90	—3·86	—4·48	—5·06	—4·52	1·26	2·63	1·84	1·10	—1·61	—2·19	—2·81	—1·81
14	—3·96	—4·36	—4·90	—5·28	—5·50	—1·21	0·19	—0·30	—0·89	—2·64	—2·34	—2·77	—2·82
15	—3·61	—4·28	—4·59	—4·84	—5·43	—2·96	—2·06	—2·23	—2·50	—2·98	—2·10	—2·33	—3·31
16	—2·76	—3·53	—3·82	—4·18	—4·86	—4·18	—3·74	—3·62	—3·54	—2·72	—1·59	—1·58	—3·34
17	—1·58	—2·41	—2·82	—3·43	—4·17	—5·06	—4·71	—4·38	—4·05	—2·18	—1·02	—0·70	—3·04
18	—0·45	—1·27	—1·80	—2·55	—3·45	—4·90	—4·93	—4·51	—4·04	—1·61	—0·54	0·00	—2·51
19	0·38	—0·32	—0·90	—1·55	—2·60	—4·54	—4·76	—4·17	—3·71	—1·16	—0·21	0·38	—1·92
20	0·30	0·27	—0·20	—0·67	—1·71	—3·96	—4·11	—3·55	—3·25	—0·84	—0·11	0·49	—1·38
21	0·97	0·66	0·26	—0·08	—0·94	—3·11	—3·50	—2·89	—2·82	—0·57	0·02	0·54	—0·95
22	1·09	0·91	0·61	0·27	—0·33	—2·69	—2·89	—2·23	—2·42	—0·30	0·19	0·66	—0·58
23	1·38	1·26	1·04	0·68	0·21	—1·91	—2·19	—1·57	—1·95	—0·03	0·36	0·92	—0·15

The following statement shows the mean differences, irrespective of sign, between the values of the southerly components (C) calculated from the formulæ and the values contained in Table IX which for reference we shall call the *observed* values (O).

Month.	Jan.	Feb.	March	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
C.—O.	0·10	0·04	0·11	0·19	0·23	0·12	0·10	0·13	0·11	0·05	0·07	0·11	0·09

Tables XIV and XV contain the constants of the periodic formulæ which represent the variations in the westerly components and Table XVI contains the values of the variations calculated from these formulæ.

Formulæ.

35. The following statement shows the mean differences irrespective of sign between the observed (O) and calculated (C) values of the westerly components.

Month.	Jan.	Feb.	March	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
C.—O.	0·08	0·10	0·21	0·24	0·16	0·18	0·13	0·12	0·15	0·06	0·07	0·08	0·10

The differences are smallest for both components during the period November to February, greatest during March to May, and intermediate for the period of the south-west monsoon June to September.

The formulæ do not satisfactorily represent the variations in the morning hours 6 to 10, when rapid changes take place especially in the westerly component.

Diagrams.

36. Plates V and VI contain diagrams formed from the data contained in Tables IX and XIII, and show the mean resultant velocity in magnitude and direction for each hour of the mean day in each month of the year and the whole year. The vector A O in each diagram represents the mean resultant of these hourly velocities, the vector N O shows the velocity corresponding to the hour N and vector N A shews the variation in velocity (in magnitude and direction) from the mean, corresponding to the hour. In fact, if the velocity of the air at each hour of the day were reduced by the velocity represented by A O, the remaining air movement at each instant would be that represented by the vectors drawn from the corresponding points on the curve to A. In most months it will be seen that A is inside the curve; thus a wind vane exposed to such an air movement would make a complete rotation during the day. This would happen in all months except in December and January.

Diurnal variations

37. The values of the southerly and westerly components given in Tables IX and XIII have not been plotted for all months but those for April, May, June and July are given in Plate IV. Taking the southerly component first it will be seen that there is an increase in its value from dawn till about 7-30 A.M. in each of those months (April excepted) and this also holds for August and September. This change is followed by a diminution till 10-30 A.M. or 12-30 P.M. when the absolute minimum for the day is reached. In the westerly component a sudden and rapid increase occurs after 6-30 A.M. and up till 10-30 A.M. and this is followed by a larger and equally rapid diminution which goes on till 5-30 P.M. or 6-30 P.M.; in fact the component becomes easterly in the early afternoon hours. These features are common to the normal air movement during all the months May to September, and April as well, though the wind does not really become westerly except for a brief period (from 7 to 9) in the morning during this month. These large changes in the two components in the early part of the day are due, as will be seen from the figures in Plate V, to a change in direction as well as in magnitude of the velocity which begins about sunrise. Now the direction N. S. and E. W. along which we have resolved the velocities have a special significance in connection with Madras, because the coast line is nearly in the direction north and south here. Hence the east and west directions are approximately the directions of the gradients for land and sea breezes—a local convection system, superposed on the general air movement. We have just seen that the westerly component increases very rapidly in the early morning during the months April to September when temperatures are highest and the increase appears to be much more rapid than it is at inland stations. It is very probable that a part of this increase is due to an increase in strength of the land wind component of the land and sea breeze system which increases in strength from 6-30 A.M. to about 10-30 A.M. Such an increase is after all only what might be expected. For in the morning hours the ground is rapidly heated and in turn the lower layers of air resting on it. With this increase in temperature of the air, the surfaces of equal pressure are raised and a rapid flow of air towards the sea takes place in the higher regions, a change which ultimately establishes the sea breeze. But before an increase in pressure at the surface of the sea takes place owing to the accumulation of air from the land side, a momentary increase has already taken place over the surface of the land itself accompanied by lateral expansion and these cause the lower layers of air to move from the land towards the sea. Hence an increase for a short time of the land wind in the morning hours is to be expected. Owing to friction, etc., at the surface of the earth and other causes the horizontal movement is of course much less and takes place much more slowly than the movement in the higher region. In May and whenever the temperature of the air over the land is at no time in the course of the day below the temperature of the air over the open ocean, the explosive kind of effect here considered is mainly responsible for the land wind.

November to February

38. Plates V and VI show the mean hourly velocity at each hour of the day for each month in the manner already explained. The variation curves formed by joining the extremities of the vectors representing the velocities at each hour are widely different for different months. In

November, December, January, and February the variation curve is long and narrow and its greatest length, its axis so to speak, is in the direction of the resultant velocity for the 24 hours. Thus during these months the wind velocity undergoes very little change in direction during the day, but large changes in magnitude. The variation curve in November is described by a clockwise rotation and one portion of it from hours marked 12 to 16 is very narrow. In December the curve consists of two loops (i) a small loop described by a counter-clockwise rotation from 12 noon to 4 P.M. and (ii) a large loop described by a clockwise rotation between the hours 4 P.M. and 12 noon following. Here the larger loop is very narrow and its axis is practically coincident with the direction of the resultant for the day; the axis of the smaller loop is more nearly parallel to the east and west line. In January the variation curve is similar to that for December. It has two loops (i) the night loop described by clockwise rotation during the hours 5-30 P.M. to 10-30 A.M. following, a long and narrow loop whose axis is parallel to the mean direction of the wind for the day (ii) the day loop described by a counter-clockwise rotation during the hours 10-30 A.M. to 5-30 P.M. whose axis is almost parallel to the east and west line. Thus the changes that take place in the daily variations in the course of these three months are in one direction, and the day loop of the variation curve grows at the expense of the night loop; in November the day loop is not formed, in December it is small, in January it is considerable and in February it has absorbed the whole curve. In November owing to the cloudy weather, heavy rain, smaller diurnal range of temperature, and large amount of vapour in the air, the land and sea-breeze must be small. But the weather improves in December, and is generally fine in January with much clearer skies, very little rainfall, less vapour and greater diurnal range in temperature. The following statement confirms these remarks; it is taken from the Madras Observatory Meteorological Means.

	Temperature range.	Mean temperature.	Vapour pressure.	Cloud.	Rainfall.
November ...	12°·7	77°·5	·748 inch	0·6	13·21 inches.
December ...	13°·8	75°·5	·683 „	0·5	5·28 „
January ...	17°·1	75°·1	·638 „	0·4	0·89 „

Thus as the season advances the conditions necessary for the development of the land and sea-breezes improve and become more effective. Their action is however greatly modified by the general air movement which tends to prevent the establishment of conditions that develop the land and sea-breeze. During February, March and April the variation curve is a similar loop described by a counter-clockwise rotation. In February the length of the curve is practically in the direction of the resultant as in the other months just considered.

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March to May.

39. In March and April the curve becomes more unsymmetrical, owing to the rapid increase in the southerly component from 6 A. M. to about 10 A. M., while the westerly component increases only very slowly.

In all the curves from November to April it will be noticed that the part from the hour 16 to 4 or 5 is very nearly a straight line which for the first four of these months coincides with the direction of the resultant, while in March and April it is inclined to the mean at an angle which increases with the season. The land and sea breeze also becomes more prominent in March and April, and the small change in the easterly component of the air movement observed from 6 to 10 A. M., at this time is due to the increase in the strength of the land wind from the west during these hours already considered; and practically balancing the simultaneous increase in the easterly component which would in the absence of the local system be observable. In May the daily variation curve is, unlike those for March and April, long and narrow, and described by a clockwise rotation. The axis of the curve is almost perpendicular to the resultant which in this month is almost southerly,—about 13° to the east of south.

June to September.

40. The same features also characterise the variation curves for June to September, but in these months the resultant is in the southwest quadrant.

The variation curve is long and narrow and its longest axis is almost perpendicular to the direction of the resultant.

In August and September the variation curve is broader both absolutely and in proportion to its length than in June and July.

These large variations in velocity both in direction and magnitude during the day in these months are to a large extent due to the land and sea-breezes, the directions of which are nearly perpendicular to the general air movement.

Classification.

41. Hence the daily variations in the air movement at Madras may be divided into three classes.

(1) Those of the months November to February which produce very little change in direction of the wind and for which the variation curve is long and narrow and almost parallel to the mean direction for the day.

(2) Those of the months March to April which produce a considorable change in direction, not however exceeding 5 points.

(3) Those of the months May to September, which produce a large change in direction of the wind, exceeding six points, and for which the variation curve is long and narrow and almost perpendicular to the coast line at Madras: the axis of the variation curve from west to east during May makes an angle of about 80° with the mean wind direction and during June to September an angle of 105° to 120°. The daily variations in October are similar to those in September and form the most important part of the

movement, but, as already explained, the means for this month combine data relating to widely different meteorological conditions and their interest is chiefly climatological.

The following features are common to the diurnal variations in all months (1) the variations during the day hours are much greater than during the night hours; the variation in the wind during the night hours in November to April is chiefly one of magnitude, the direction undergoing very little change; during the rest of the year however the variation at these hours is chiefly one of direction, the magnitude undergoing but little change, (2) a sudden change in velocity occurs shortly after sunrise throughout the year; from November to February the change in direction is small; in March to April it is considerable and in May to September it is large; throughout the year a rapid change occurs in the magnitude at this hour.

Land and sea-breeze.

42. It has already been stated that the large differences in the daily variations of the wind velocity, more particularly those in direction, are principally due to the strength of the land and sea-breeze system. This system is very small in November to February, increases rather rapidly in March and April and is most strongly in evidence during the period May to September. If the land and sea-breeze were absent the daily variations in velocity at Madras would be chiefly changes in magnitude as in November to February. At Bangalore and Trichinopoly for instance during the southwest monsoon period there is very little change in direction during the day, the changes being chiefly in magnitude alone. Hence if these variations were subtracted from the observed variations, the residuals would give us the land and sea-breeze system at each hour of the day. But the question is how shall we evaluate the diurnal variations in velocity which would take place if the local system were absent?

Method of evaluating.

43. To enable this to be done, it is necessary to form some hypothesis and the simplest hypothesis, is to assume that the variations in strength which would occur in such a case would take place in accordance with the values given in Table VII for each month. The mean wind velocity in magnitude and direction for each month or rather their westerly and southerly components are given in Tables IX and XIII as well as the observed component velocities for each hour. If we subtract from the observed component velocities for each hour, the values of the components calculated in accordance with the above hypothesis, the residuals will give us the components of the land and sea-breeze system for each hour. These considerations seem reasonable as a first approximation, the main point in the hypothesis being the assumption that the changes in wind velocity would in the case imagined take place in accordance with the relations shown in Table VII. It would have been better perhaps to have deduced these changes from the actual observed changes at an inland station where the general temperature conditions are similar to those at Madras or to take data on selected dates. But such data are not available at present, and a glance at Plates 37 to 62 of the Climatological Atlas will show how difficult it is to find a suitable inland station for this purpose. It is also probable that the assumption that the velocity only undergoes a change in magnitude and no

change in direction is not strictly warranted; but it is very probable that the error due to this is not great, for the southwest monsoon period. Further considerations are given in §47.

Land and sea-breeze in July.

44. The following statement shows the observed components and the components calculated by the ratios given in Table VII throughout the day for the month of July. The differences given in the columns headed O-C are on the above hypothesis the components of the land and sea-breeze.

JULY.

	WESTERLY COMPONENT.			SOUTHERLY COMPONENT.		
Hour.	Observed. O.	Calculated. C.	O-C.	Observed. O	Calculated. C.	O-C.
0	2·9	3·8	−0·9	5·1	3·2	1·9
1	3·7	3·8	−0·1	4·9	3·2	1·7
2	4·2	3·4	0·8	4·3	2·9	1·4
3	4·5	3·4	1·1	3·8	2·9	0·9
4	4·6	3·4	1·2	3·5	2·9	0·6
5	4·7	2·9	1·8	3·0	2·5	0·5
6	4·7	2·9	1·8	3·0	2·5	0·5
7	6·5	3·8	2·7	3·3	3·2	0·1
8	8·6	4·6	4·0	2·8	3·9	−1·1
9	10·1	5·5	4·6	1·7	4·6	−2·9
10	10·6	5·5	5·1	0·8	4·6	−3·8
11	10·1	5·9	4·2	0·4	5·0	−4·6
12	8·9	5·5	3·4	0·2	4·6	−4·4
13	7·1	5·5	1·6	0·7	4·6	−3·9
14	4·5	5·0	−0·5	1·8	4·3	−2·5
15	2·0	5·0	−3·0	3·1	4·3	−1·2
16	0·4	4·6	−4·2	4·2	3·9	0·3
17	−0·4	4·2	−4·6	5·0	3·6	1·4
18	−0·7	3·8	−4·5	5·3	3·2	2·1
19	−0·4	3·8	−4·2	5·7	3·2	2·5
20	0·1	3·8	−3·7	5·9	3·2	2·7
21	0·8	3·8	−3·0	5·8	3·2	2·6
22	1·3	3·8	−2·5	5·6	3·2	2·4
23	1·9	3·8	−1·9	5·4	3·2	2·2

If these values be plotted as in Plate VI fig. for July we get an oval figure; the vectors from any point of the boundary of this figure to the origin denote in magnitude and direction the velocity due to the land and sea breeze system which we are trying to evaluate. The longest axis of this curve makes an angle of about 32° with the east and west line. The coast line at Madras makes an angle of about 15° with the meridian to the east of north. Hence the axis of this curve is not perpendicular to the coast line but makes an angle of about 17° to the north of west with it. This is also approximately the angle that the mean direction of the wind at Madras in July makes with the normal to the isobar or the gradient. According to this diagram the land and sea breeze in July goes through the following changes. At about 7 A.M. the wind is westerly. It increases rapidly in strength and veers to the north-west till about 11 A.M. when the velocity is a maximum and direction approximately north-west. From this hour the velocity diminishes and the direction goes on changing towards the north and is northerly at about 2 P.M. The change in direction from 1-30 P.M. to 4 P.M. is rapid and after 2·45 P.M. the velocity increases again to a maximum at about 6·30 P.M., when the direction is about S. 74° E. From this hour the velocity diminishes in magnitude till about 4·30 A.M. and becomes more southerly in direction, being southerly between 1 and 2 A.M. The change in direction goes on more or less regularly till it is westerly at 7 A.M. From 4 or 5 A.M. it begins to increase in magnitude again. All these changes are what we would be led to expect if there was an alternating movement of air between the land and sea, the veering shown being due to the well known action of the rotation of the earth.

Time of incidence of sea breeze.

45. If the air movement were that due to the land and sea breeze system alone then according to these results the sea breeze would not set in at the observatory till about 2-30 P.M., a somewhat late hour according to accepted notions. Perhaps too much stress should not be placed on this, and the lateness of the hour may in part be due to the imperfection of the hypothesis. On the other hand it is well to remember that the observatory where the records under discussion were taken is at least three miles from the sea and the time the breeze from the sea begins to affect the air movement at such a station is materially later than on the coast line itself. In fact it is a common enough observation at Madras during the southwest monsoon period to find a cool sea breeze on the Marina while at the observatory the air movement is still from the land; and on some days there is no sea breeze at all at the observatory while it has set in fairly early on the beach and continues throughout the afternoon. Another consideration is that the gradients necessary to establish a sea breeze at Madras when a strong southwest wind is blowing must be much steeper than when the southwest wind is light. Hence to bring about these pressure conditions under given temperature conditions a longer time is necessary with a strong southwest wind than with a light one. Thus the late hour at which the sea breeze sets in is partly due to this cause. Note that in May when the mean direction is southerly, the sea breeze begins to affect the movement at the observatory at 12 noon. *See* Table XVII.

Abnormal rotation of wind vane.

46. This diagram giving the velocity of the land and sea breeze system at different hours of the day suggests an

explanation of another phenomenon sometimes observed at Madras, and that is that occasionally during the latter half of May and from June to September, the wind changes from its westerly direction in the morning to an easterly direction in the afternoon *through north* instead of through south, the normal and usual course of the change, as may be seen from the diagrams in Plates V and VI. This is generally observed on very hot days when the air movement is much below the average. It will at once be evident that under these conditions an unusually large and strong sea breeze such as would be expected under the excessive temperature conditions is superposed on an unusually weak general air movement. In this case the velocities due to the local convection system between 10 A.M. and 5 P.M. are much greater than usual and are sufficient to give a resultant air movement from the north instead of from the south and the wind vane veers through north from west to east in consequence. The vigorous movement due to the local convection system is in fact sufficient to overpower the feeble general air movement on which it is superposed. When the wind changes from west to east through north the change usually takes place, it is observed, between 11 A.M. and 1 P.M. This observation also fits in with the explanation of the phenomenon given above.

Components of the land and sea breeze.

47. The values of the components of the land and sea breeze system have been worked out by the method explained in Sections 42-43; those for the months May to October are given in Table XVII. In the months November to March the residuals are small and irregular, indicating that the hypothesis is imperfect. During these months small but relatively important changes occur in the direction of the wind during the day with the changes in the pressure distribution. The land and sea breeze system is probably small. In April the residuals are somewhat larger but still very irregular. Plate 14 of the Climatological Atlas shows that the pressure distribution undergoes large changes in the course of the day in this month and with these there must be considerable changes in the direction of the wind. Hence the method is not suitable for this month also. The land and sea breezes are much stronger than in the preceding months. From May to September or October the diurnal changes in the pressure distribution are *relatively* not so large and important and do not involve large changes in the direction of the wind at Madras. The residuals for these months are large and when plotted give diagrams similar in their principal features to that for July shown in Plate VI, fig. for July. While it would be too much to assert that these represent completely the land and sea breeze system, they at least indicate an important part of it.

It has been already remarked that the land and sea breezes are feeble in the cold weather, increase to their maximum in May, June and the first part of July, and then diminish to a minimum about November.

TABLE XVII.—*Components of the land and sea breeze hourly velocities.*

Hour.	May.		June.		July.		August.		September.		October.	
	E.	S.	W.	S.	W.	S.	W.	S.	W.	S.	E.	N.
0	−0·7	1·5	−0·1	2·0	−0·9	1·9	−0·5	2·5	−0·8	2·2	−1·1	−0·2
1	−1·2	1·0	0·4	1·3	−0·1	1·7	0·4	2·1	−0·4	2·2	−0·4	−0·3
2	−1·4	1·3	1·3	1·1	0·8	1·4	0·5	1·6	0·0	1·8	−0·9	−0·4
3	−1·5	1·1	1·7	0·7	1·1	0·9	1·3	1·5	0·7	1·6	−0·9	−0·4
4	−1·6	0·7	1·8	0·3	1·2	0·6	1·2	1·1	1·3	1·5	−1·0	−0·3
5	−1·9	0·3	2·1	0·5	1·8	0·5	1·5	1·1	1·3	1·0	−1·1	−0·3
6	−2·2	0·9	2·0	0·1	1·5	0·5	1·7	0·9	1·7	1·0	−1·2	−0·6
7	−4·2	0·1	3·3	0·0	2·7	0·1	2·2	0·6	2·7	0·7	−1·5	−0·8
8	−6·2	−1·1	4·7	−1·5	4·0	−1·1	3·5	−0·5	5·2	−0·6	−2·4	−0·6
9	−6·4	−2·2	5·7	−3·1	4·6	−2·9	4·6	−2·1	4·7	−2·3	−2·7	−0·3
10	−4·5	−2·9	5·3	−4·4	5·1	−3·8	4·8	−3·7	4·6	−3·0	−2·4	0·2
11	−1·1	−2·7	4·1	−4·5	4·2	−4·6	4·2	−4·1	3·9	−3·5	−1·5	0·4
12	1·9	−1·6	2·4	−3·6	3·4	−4·4	2·9	−4·1	2·4	−3·4	−0·2	0·8
13	4·0	−1·3	−0·1	−3·3	1·6	−3·9	1·1	−3·5	0·5	−2·5	1·5	0·6
14	4·7	−0·5	−2·2	−2·3	−0·5	−2·5	−1·1	−2·7	−1·5	−2·4	2·4	0·6
15	5·1	−0·2	−3·7	−0·5	−3·0	−1·2	−2·8	−1·5	−3·1	−1·4	2·7	0·6
16	4·7	0·4	−4·9	1·0	−4·2	0·3	−4·1	−0·3	−3·9	−0·3	2·7	0·5
17	3·9	0·0	−4·9	1·7	−4·6	1·4	−4·4	0·6	−3·8	0·3	2·1	0·5
18	3·3	0·8	−4·6	1·5	−4·5	2·1	−3·7	1·2	−3·7	0·9	1·6	0·2
19	2·6	0·9	−4·0	2·4	−4·2	2·5	−3·5	1·5	−2·9	1·1	1·2	0·3
20	1·8	0·8	−3·9	2·6	−3·7	2·7	−3·2	1·9	−2·6	1·3	1·0	0·1
21	1·1	0·9	−3·1	2·7	−3·0	2·6	−2·5	2·0	−2·1	1·3	0·6	−0·1
22	0·5	1·4	−2·2	2·6	−2·5	2·4	−1·9	2·2	−2·1	1·6	0·5	−0·2
23	−0·1	1·0	−1·4	2·2	−1·9	2·2	−1·1	2·5	−1·3	1·9	0·2	−0·2

Concluding note.

48. This concludes the discussion of the normal air movements at Madras. It is not possible at present to deal with the abnormal winds nor to analyse the records on selected days. Apart from its importance from a climatological point of view, this treatment promises to throw further light on several points considered in this discussion especially on the determination of the land and sea breezes. These matters may form the subject of a subsequent paper.

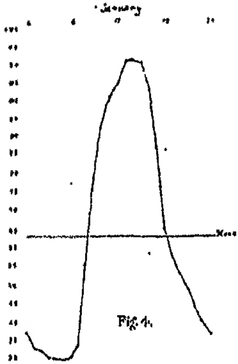


Fig. 4.

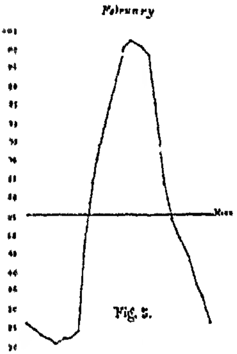
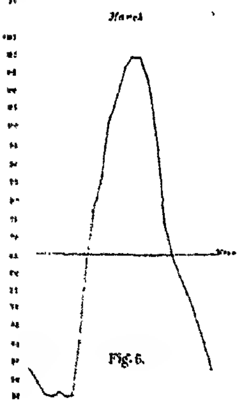


Fig. 5.



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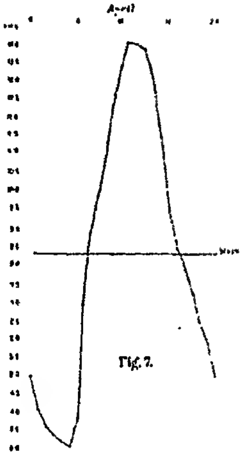

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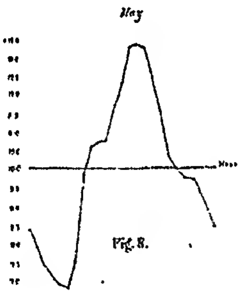

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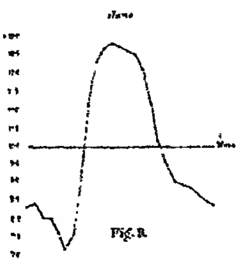

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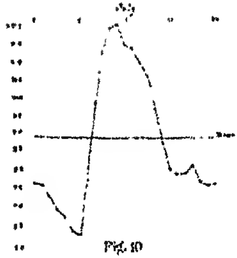

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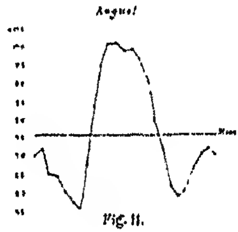

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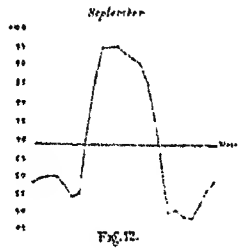

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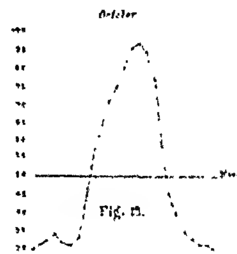


Fig. 13.

WIND ROSES SHOWING THE PERCENTAGE NUMBER OF CALMS AND OF MILES OF WIND IN THE DIFFERENT DIRECTIONS DURING SEVERAL MONTHS AT MADRAS.

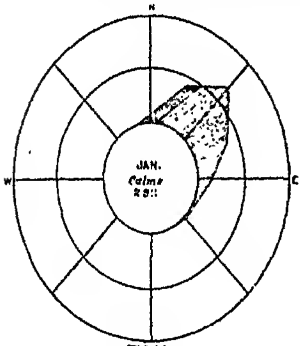


Fig. 14.

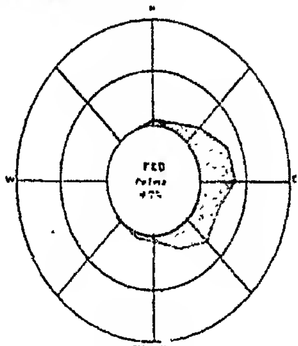


Fig. 15.

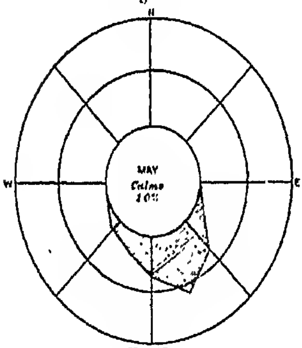


Fig. 16.

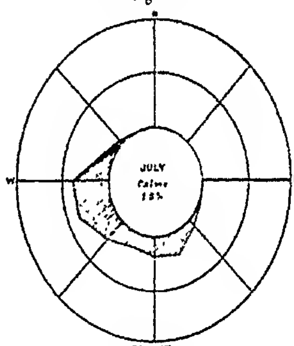
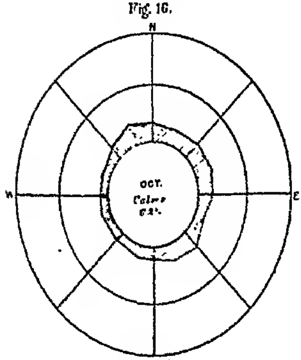


Fig. 17.



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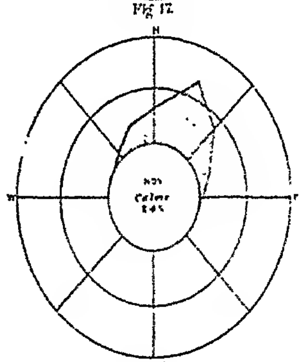

Fig. 19.

Mean hourly southerly components

April

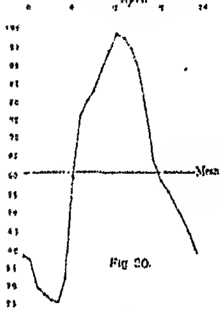

Fig. 20.

May

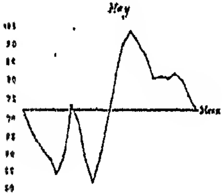

Fig. 21.

June

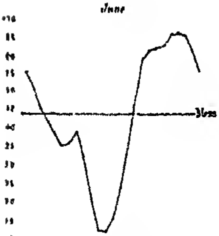

Fig. 22.

July

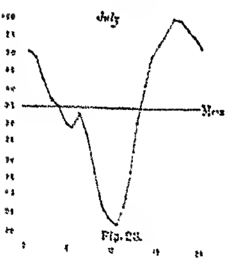

Fig. 23.

Mean hourly westerly components

April

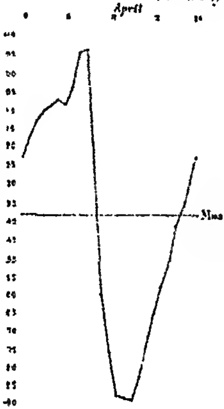

Fig. 24.

June

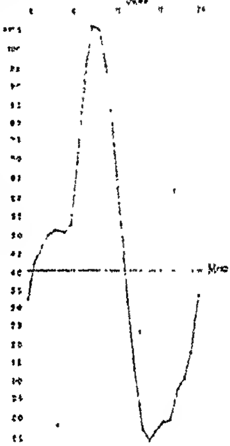

Fig. 25.

May

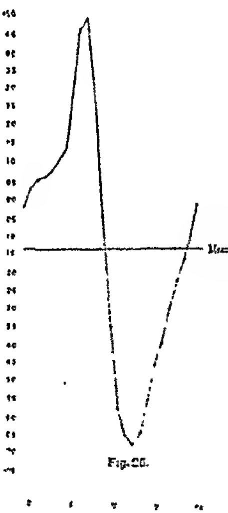

Fig. 26.

July

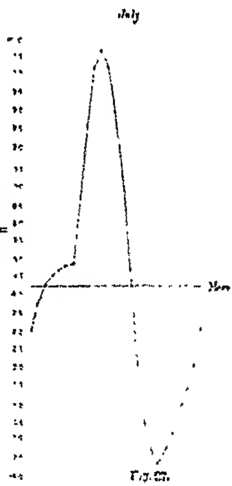

Fig. 27.